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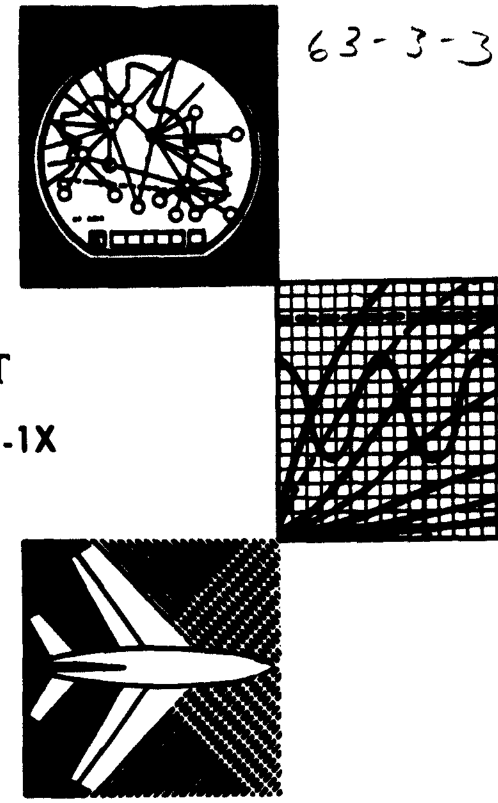

FINAL REPORT

Project No. 202-2-1X

# STUDIES IN THE FIELD OF APPROACH VISIBILITY MEASUREMENT & INSTRUMENTATION

APRIL 1962



This report has been approved for general distribution

Prepared by:
U. S. Department of Commerce, Weather Bureau
Under
FAA/Weather Bureau Project Agreement FAA/BRD-A-51

**FEDERAL AVIATION AGENCY**
Systems Research & Development Service
**EXPERIMENTATION DIVISION**
Atlantic City, New Jersey

# FINAL REPORT

## STUDIES IN THE FIELD OF APPROACH VISIBILITY MEASUREMENT AND INSTRUMENTATION

PROJECT NO. 202-2-1X

Prepared by:

Matthew Lefkowitz
and
Aviation Weather Research Project Personnel
U. S. Weather Bureau

Under Project Agreement FAA/BRD-A-51

April 1962

This report has been prepared by the U. S. Department of Commerce Weather Bureau as a joint project with the Systems Research and Development Service, Federal Aviation Agency, under FAA Project Agreement FAA/BRD-A-51. As an experimental effort, the contents do not necessarily reflect the official policy of either agency at this time.

FEDERAL AVIATION AGENCY
Systems Research and Development Service
Experimentation Division
Atlantic City, New Jersey

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Federal Aviation Agency, Atlantic City, N. J.
STUDIES IN THE FIELD OF APPROACH VISIBILITY MEASUREMENT AND INSTRUMENTATION by Matthew Lefkowitz, April 1962, 150 pp. including 48 illus. and 21 tables, Final Report
(Project No. 202-2-1X)


## ABSTRACT

A series of studies have been conducted and developmental work performed in the field of approach visibility measurements, instrumentation, and application to aircraft instrument landing operations, at the National Aviation Facilities Experimental Center, Atlantic City, New Jersey.

Flight tests were conducted in a comprehensive program designed to refine the approach light contact height (ALCH) techniques developed empirically at Newark and confirm their more general applicability to other locations, types of aircraft and operational conditions. It was determined that ALCH for low clouds was substantially the same at Atlantic City as at Newark. Limited data for ALCH, HF category (fog, smoke, and haze), permitted the general appraisal that this category also showed marked similarity.

Studies indicated that automatic control of runway and approach lights is feasible, and a design was developed for optimum intensity of these lights with regard to varying weather conditions. This design was based on the concepts of runway visual range (RVR) and ALCH to provide a means of immediate and practical application.

Four simultaneously operating transmissometers were installed along runway 13-31 to measure variations of transmittance with time and space. Statistical studies were made of the data. It was revealed that a measurement made by a transmissometer cannot be relied on to be more representative than the immediate area sampled; hence, it is not always representative of conditions encountered by the pilot as he moves along the runway during landing and takeoff operations.

## INTRODUCTION

The problems of terminal weather reporting and the instrumentation by which terminal weather is measured, still exist as limiting factors to economy, convenience, and safety in the field of aircraft operation. To help provide solutions to these problems, the U. S. Weather Bureau (USWB) has participated in a joint project with the Federal Aviation Agency (FAA) to conduct studies and perform developmental work in the field of approach visibility measurements, instrumentation, and application to aircraft instrument landing operations. For these purposes a meteorological test facility was established in August 1959 at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, N. J.

The interagency Project Agreement FAA/BRD-A-51 designated the USWB to furnish personnel, procure equipment, conduct tests and evaluation of equipments for determining approach visibility and to report the results. The FAA provided funds for personnel and equipment, and in addition supplied operational, test, and management support.

The meteorological test facility designated as the Aviation Weather Research Project (AWRP) conducted investigations from August 1959 through August 1961. This report details technical procedures, results, and pertinent data, and provides a final summary of all important work performed.

# INSTRUMENTATION

## General

The instrumentation utilized at Atlantic City were those units transferred from the established Newark Project (Reference 1) and several instruments especially fabricated. The instrumentation is discussed in this report as Conventional and Specialized. The locations of the field sensors are shown in Fig. 1.

## Conventional Instrumentation

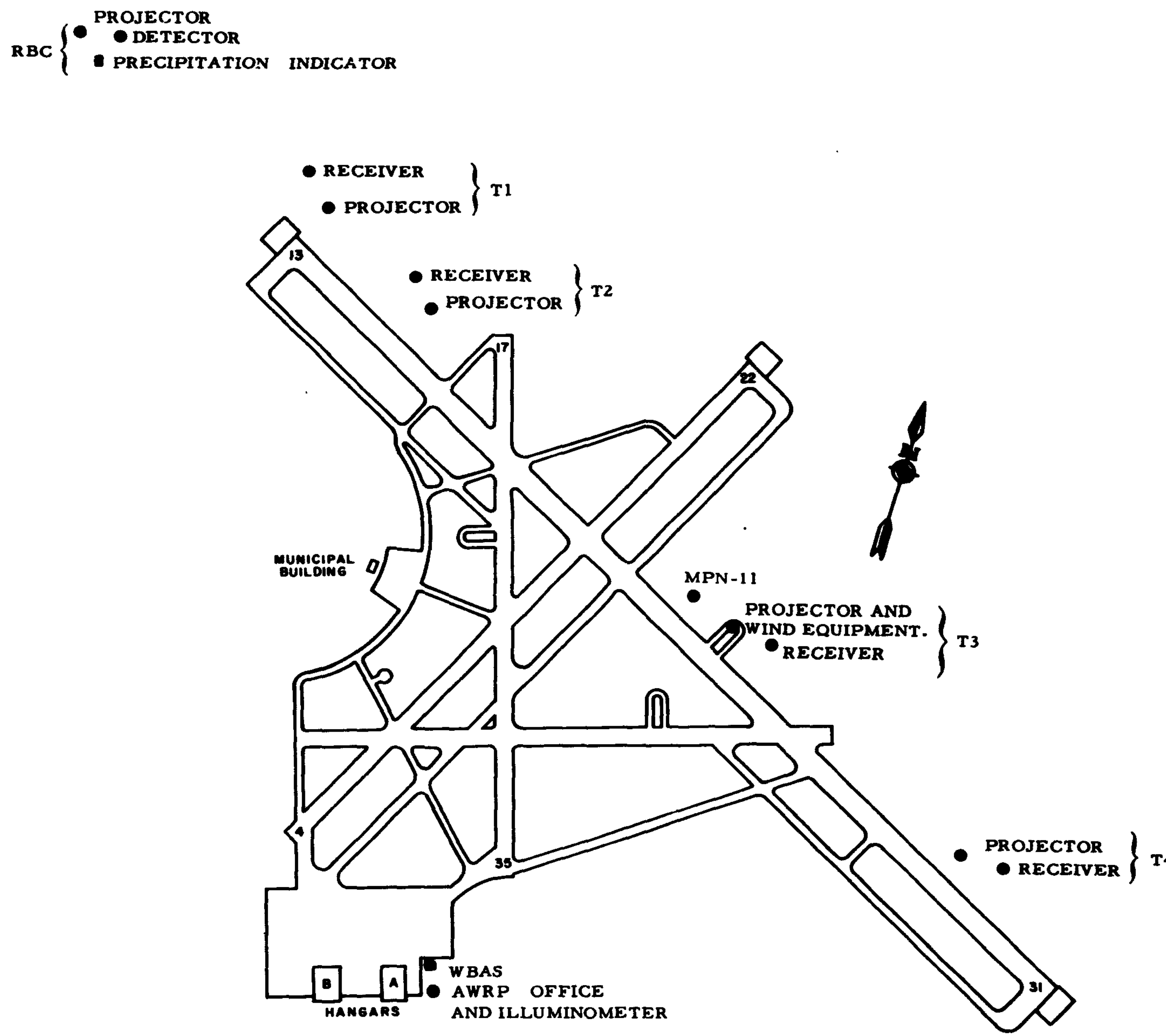
### 1. Transmissometers

Four transmissometer systems, T1, T2, T3, and T4, were installed along runway 13-31 (Fig. 2). T2 was used in the ALCH investigations. All systems were on 500-foot baselines and provided data for the variation of transmittance studies. The projectors (Fig. 3), and receivers (Fig. 4), were mounted atop 14-foot towers; the signals from the field sensors were received in the data acquisition room on standard recorders (Fig. 5). The recorders were calibrated daily and prior to each period of data collection. On each recorder the left chronograph pen indicated five-minute intervals derived from a master timing system. The right pen recorded the radar display camera pulses at the instant of a pilot's report. Each transmissometer receiver was equipped with a special blower system to inhibit snow accumulation, ice accretion, and heat shimmer (Fig. 4).

### 2. Rotating-Beam Ceilometer

The rotating-beam ceilometer system (RBC) was located at runway 13 middle-marker on a 400-foot baseline and the projector faced 083° true. Figures 1 and 6 show the RBC location in relationship to other instrumentation on the airfield. The NAFEC field installation is shown in Fig. 7.

The RBC light beam modulator shutters were equipped with special synchronous motors as part of the RBC discriminator investigations. The detector signal was transmitted to the data acquisition room and to the Weather Bureau Airport Station (WBAS) where it was used for official observations. Figure 8 shows the standard indicator in the data acquisition room equipped with an




LOCATION OF FIELD SENSORS

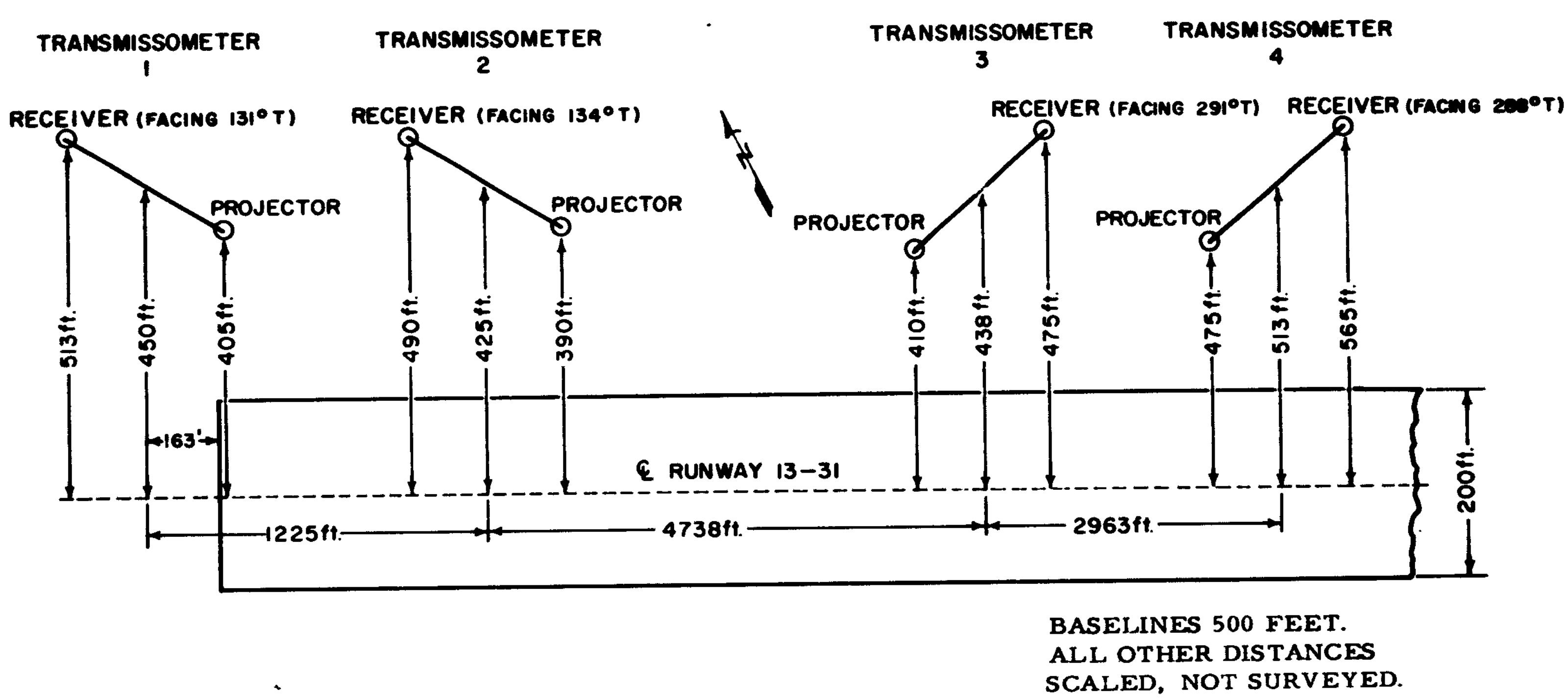



FIG. 2 RELATIVE LOCATION OF TRANSMISSOMETER SYSTEMS ALONG RUNWAY 13-31


FIG. 3 TRANSMISSOMETER PROJECTOR - WIND SYSTEM DETAIL

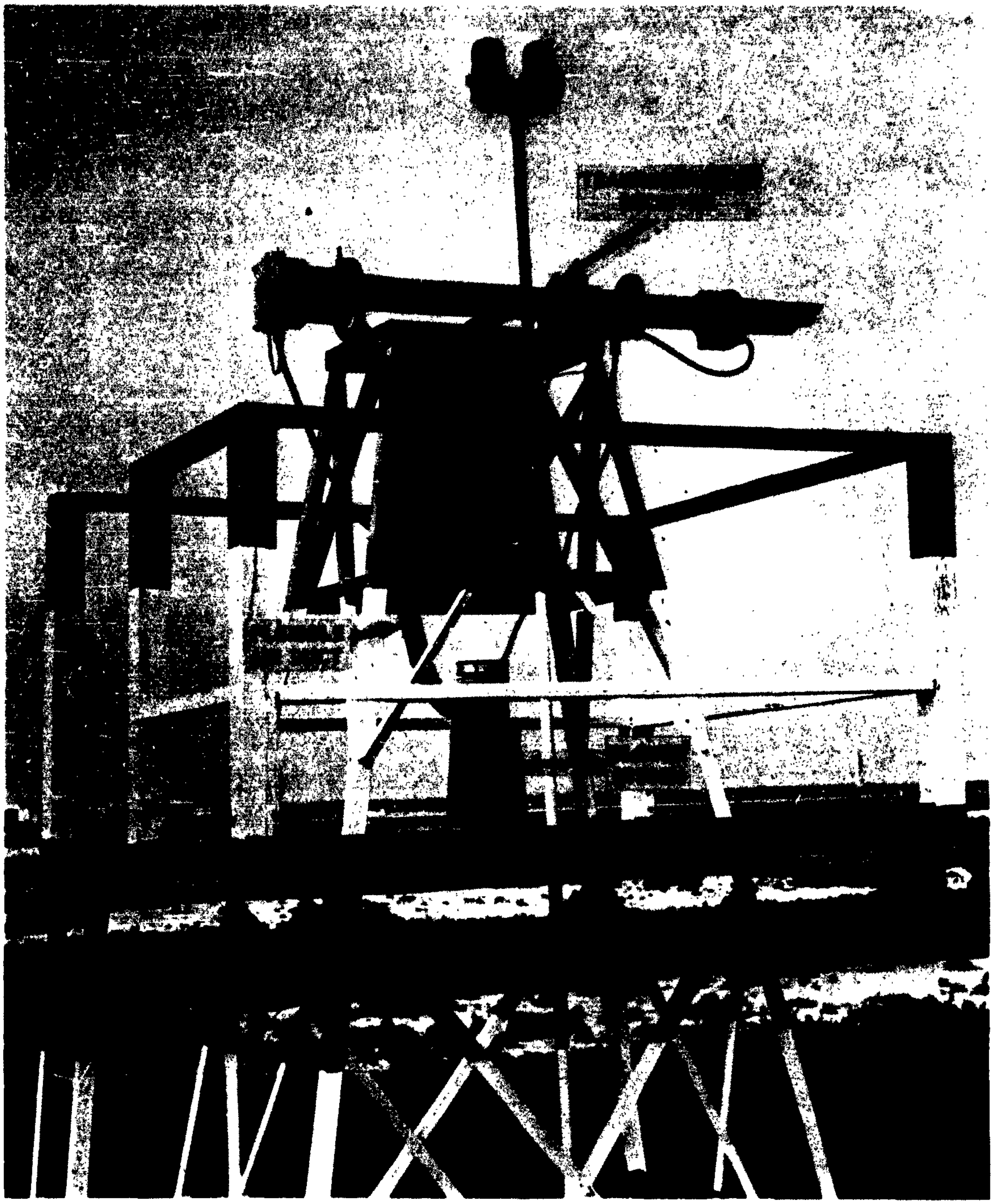
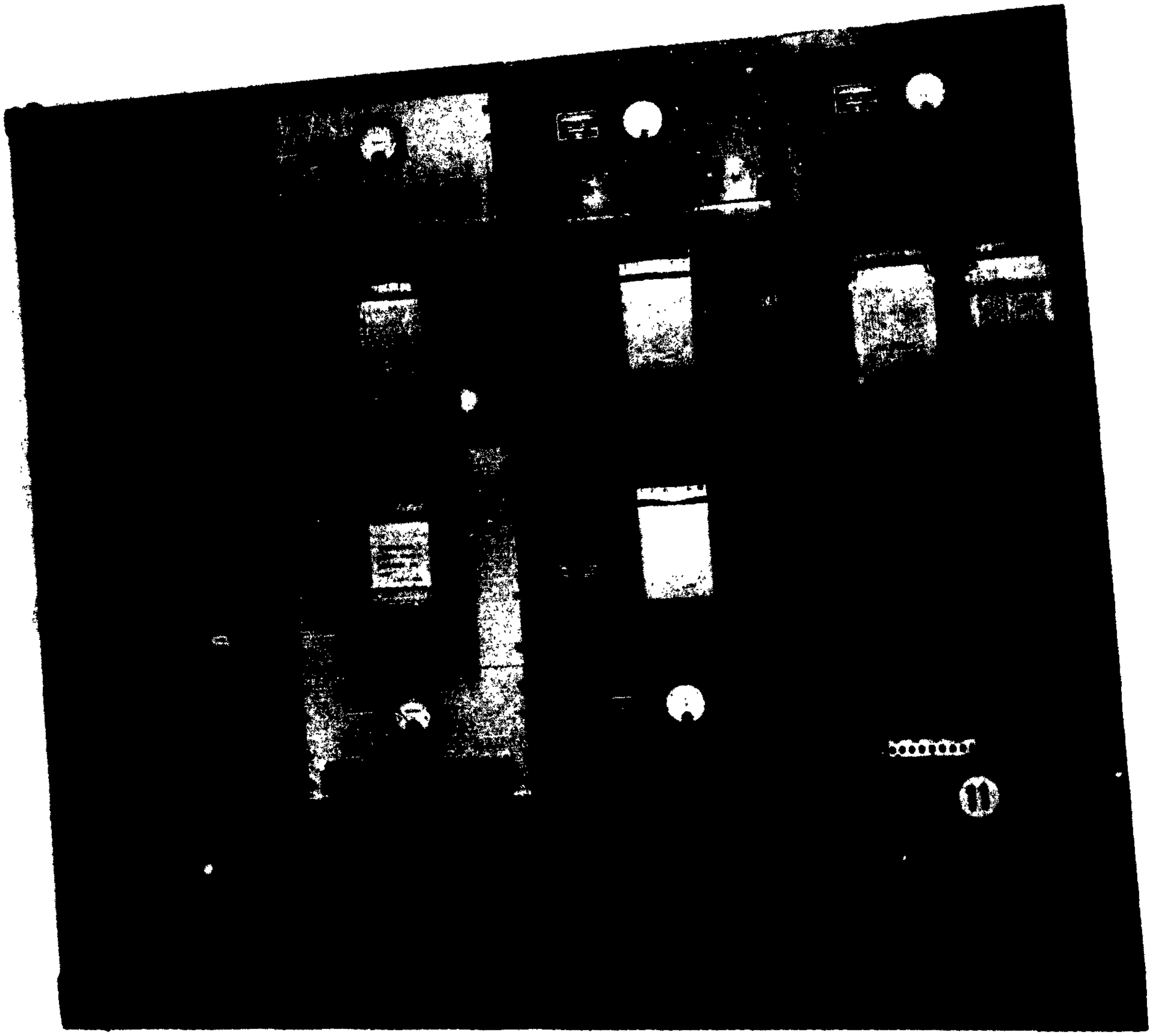


FIG. 4 TRANSMISSOMETER RECEIVER - BLOWER SYSTEM DETAIL




1. TRANSMISSOMETER BACKGROUND COUNTER
2. TERRAIN ILLUMINOMETER RECORDER
3. VHF RECEIVERS
4. PRECIPITATION INDICATOR CONTROL
5. TRANSMISSOMETER 1 RECORDER
6. TRANSMISSOMETER 2 RECORDER
7. TRANSMISSOMETER 3 RECORDER
8. TRANSMISSOMETER 4 RECORDER
9. OPERATIONS RECORDER
10. NON-LINEAR TRANSMISSOMETER RECORDER
11. READOUT FOR VISUAL DISTANCE COMPUTER

FIG. 5 DATA ACQUISITION RACKS

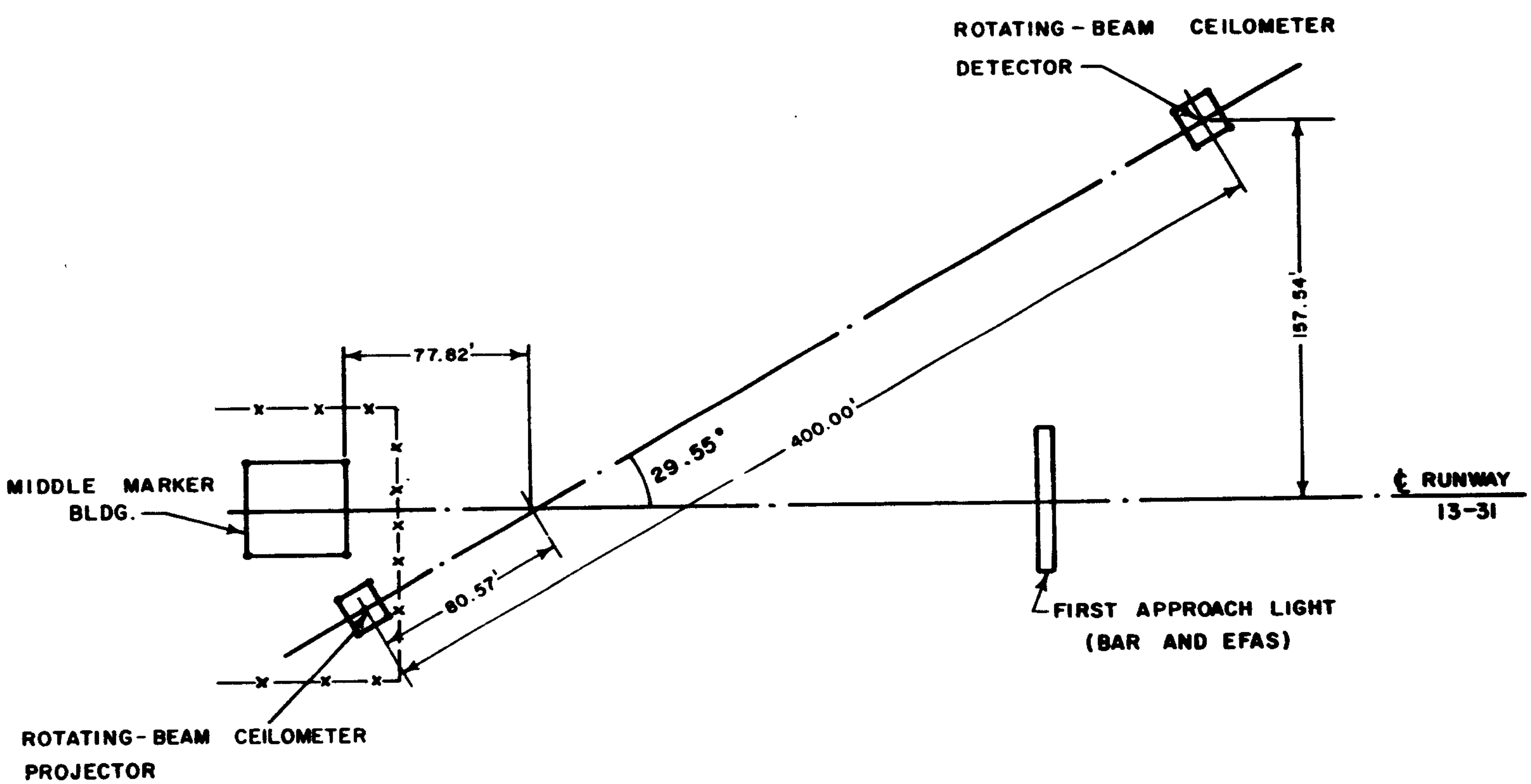



FIG. 6 LOCATION OF MIDDLE MARKER ROTATING-BEAM CEILOMETER

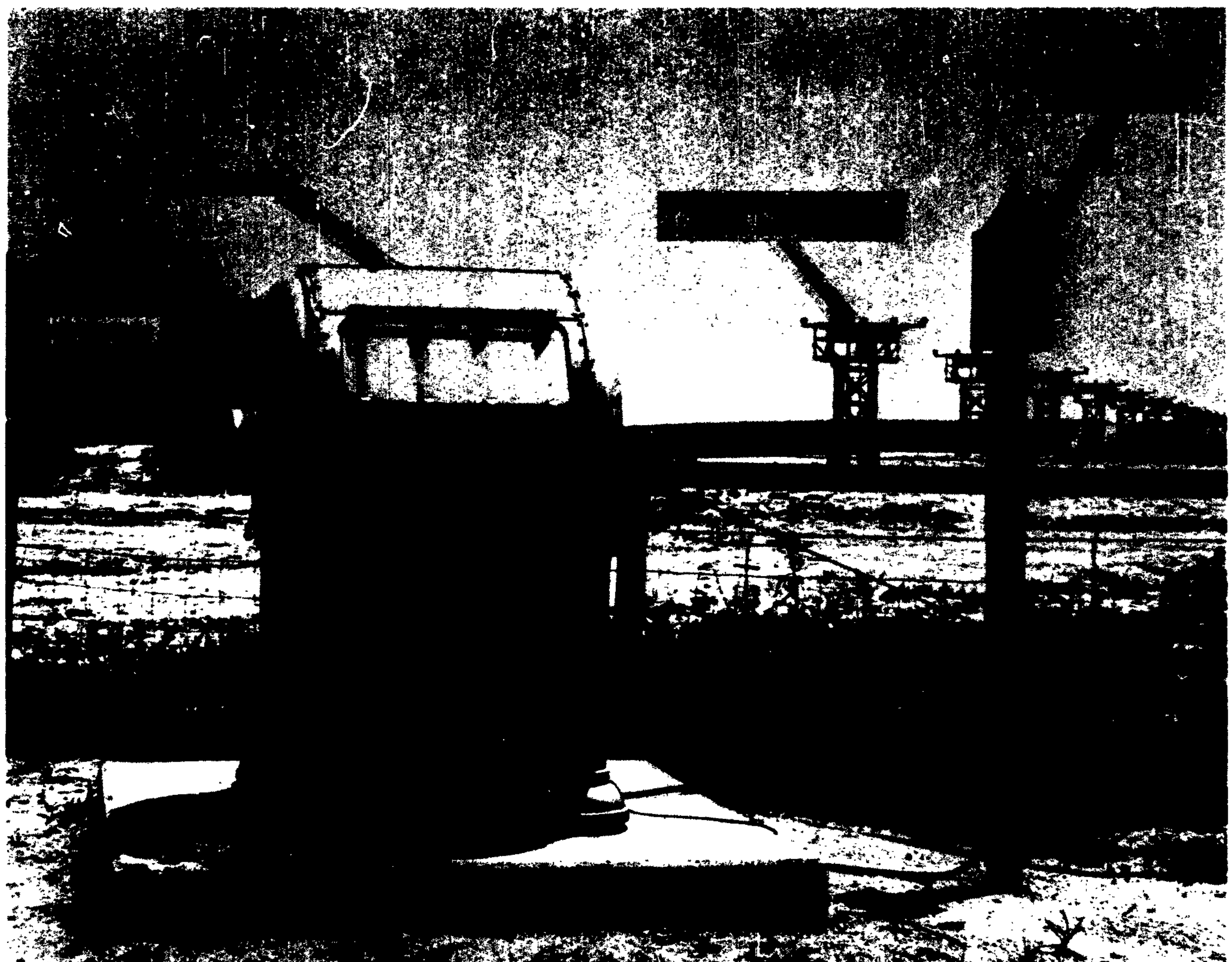
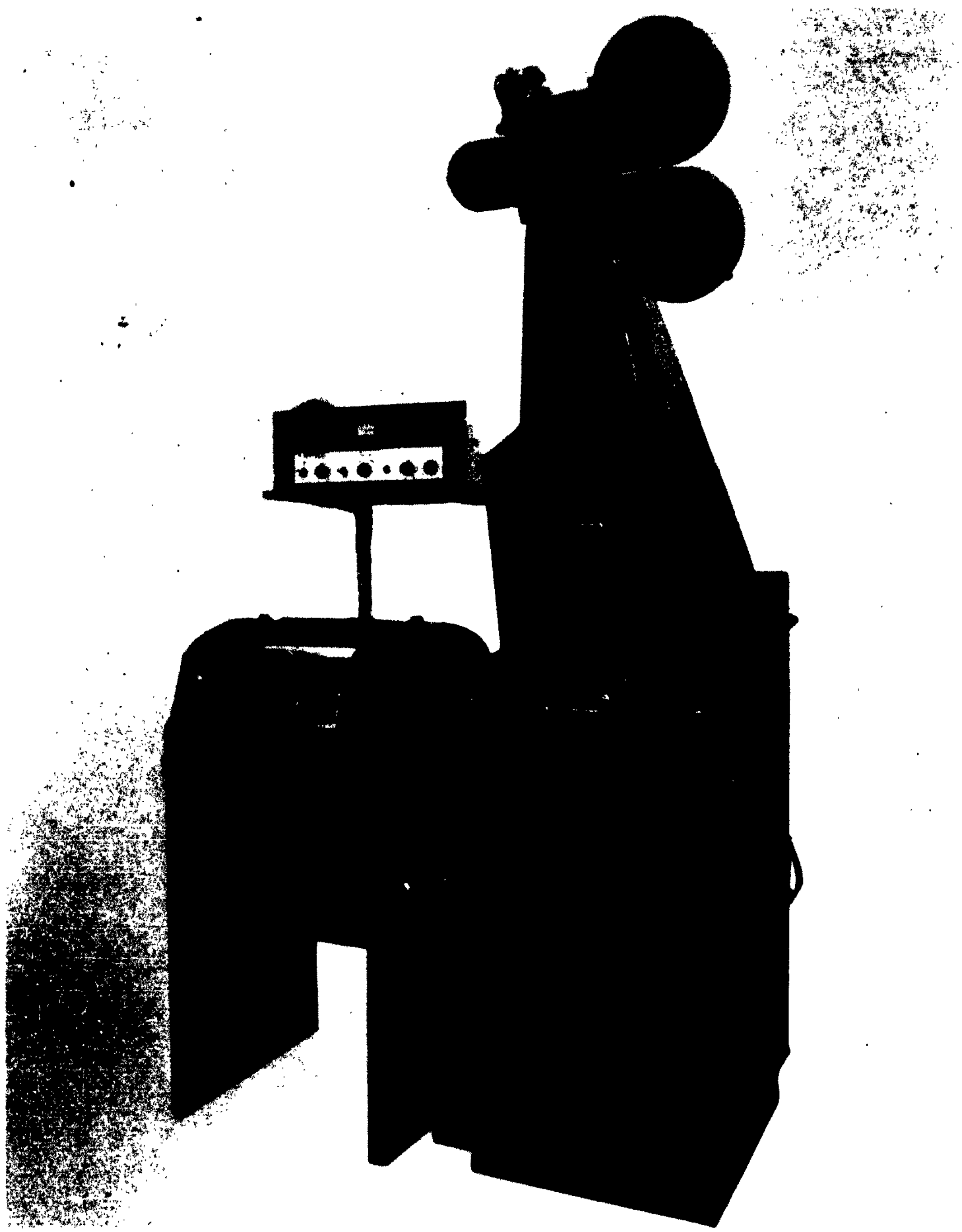


FIG. 7 FIELD INSTALLATION OF ROTATING-BEAM CEILOMETER PRECIPITATION INDICATOR DETAIL



ROTATING-BEAM CEILOMETER DISCRIMINATOR
[illegible]AL DISTANCE COMPUTER RECORDER
[illegible]ATING-BEAM CEILOMETER INDICATOR AND CAMERA

FIG. 8 PART OF DATA ACQUISITION EQUIPMENT

oscilloscope recording camera. Photographs were made of cloud height indications at 6-second intervals during test flight approaches. Included in the photographs were a digital clock and a cue at the time of the pilot report.

3. Terrain Illuminometer

A sensing head atop the project building detected the illuminance falling on a horizontal surface. The signal was recorded in the data acquisition room on a strip chart recorder equipped with a chronograph pen indicating the time of a pilot report.

4. Day/Night Switch

Located atop the project building, this instrument was used in lieu of the terrain illuminometer for most analyses; day/night was based on a transition point of about 1 foot-candle.

5. Center-of-Field Wind Equipment

Wind system F420C was located atop the T3 projector with sensors 20 feet above ground level. Wind speed, direction, and master timing pulse were recorded at the field site (Fig. 9).

6. RO-57 Cloud Height Computer

Utilizing the signal from the rotating-beam ceilometer, this unit digitized cloud height (Fig. 10).

## Specialized Instrumentation

1. MPN-11 Ground Control Approach Radar

This facility, shown in Fig. 11, was used to obtain the position of the aircraft at the time of the pilot report. A remotely controlled data camera photographed the azimuth and elevation oscilloscopes at the instant of report.

2. Radar Camera Control

A fixed frequency transmitter in the data acquisition room (Fig. 12) and a receiver in the MPN-11 radar unit enabled the project meteorologist to operate the radar camera at the instant of a report

FIG. 9 WIND RECORDER AT TRANSMISSOMETER 3

① RO-57 CLOUD HEIGHT COMPUTER
② VISUAL DISTANCE COMPUTER

FIG. 10 PORTION OF DATA ACQUISITION EQUIPMENT

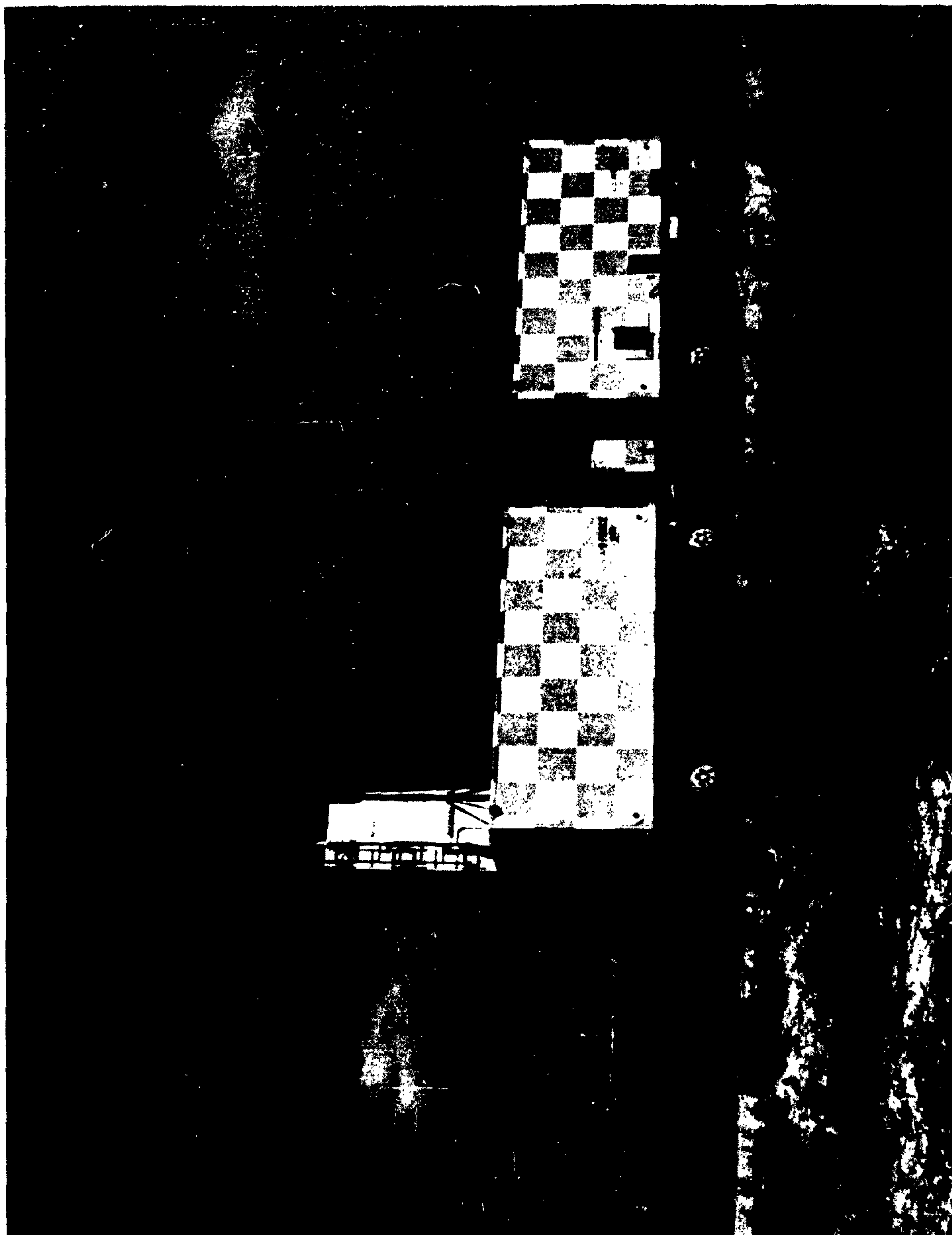


FIG. 11 MPN-11 GCA TRAILER

① TAPE RECORDERS
② RADAR CAMERA SIGNAL TRANSMITTER
③ VISUAL RANGE COMPUTER READOUT
④ COMMUNICATIONS RECEIVERS
⑤ ALCH TRANSMITTER
⑥ RUNWAY AND APPROACH LIGHT INTENSITY INDICATORS

FIG. 12 COMMUNICATIONS CONSOLE

of a pilot's contact with the light targets. The camera signal also activated two digital counters, one in the field of view of the camera in the GCA trailer (Fig. 13) and the other in the data acquisition room, to insure synchronization of the data. The signal cued the rotating-beam ceilometer camera and activated marking pens on the illuminometer, operations, and transmissometer recorders.

3. <u>Rotating-Beam Ceilometer Discriminator</u>

A developmental model of the discriminator (Fig. 8) provided by the USWB's Instrumental Engineering Division was used in an attempt to eliminate the interference of the electronic flashing approach light systems.

4. <u>Precipitation Indicator</u>

This instrument (Fig. 14) was located at the middle-marker, approximately 3270 feet from runway 13 threshold. The signal was received in the data acquisition room as a yes/no indication of the occurrence of precipitation. A yes signal within 2-1/2 minutes prior to or after a pilot's report of contact was considered indicative of precipitation as being the aircraft's environment.

5. <u>Approach Light Contact Height Transmitter</u>

A selector panel (Fig. 12) in the data acquisition room permitted the project meteorologist to transmit observational values of approach light contact height to a digital readout in the air traffic control tower for relay to incoming pilots.

6. <u>Approach and Runway Light Indicator</u>

This display (Fig. 12) provided the project meteorologist with the intensity settings of all conventional light targets available to the pilot on approach to runway 13.

7. <u>Background Counter</u>

An automatic device to count the contribution of background noise to the transmissometer systems (Fig. 5).

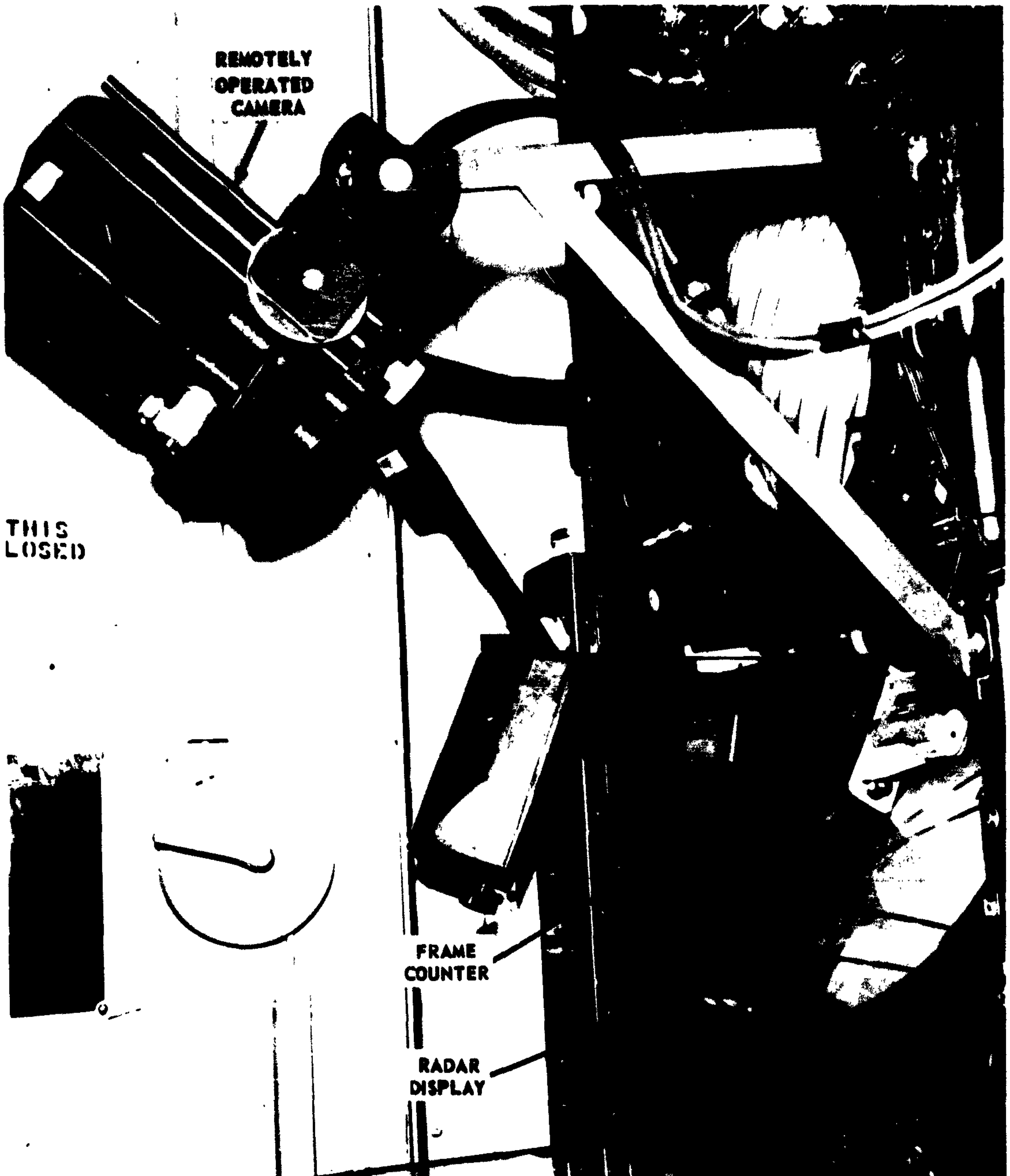



FIG. 13 INTERIOR GCA TRAILER

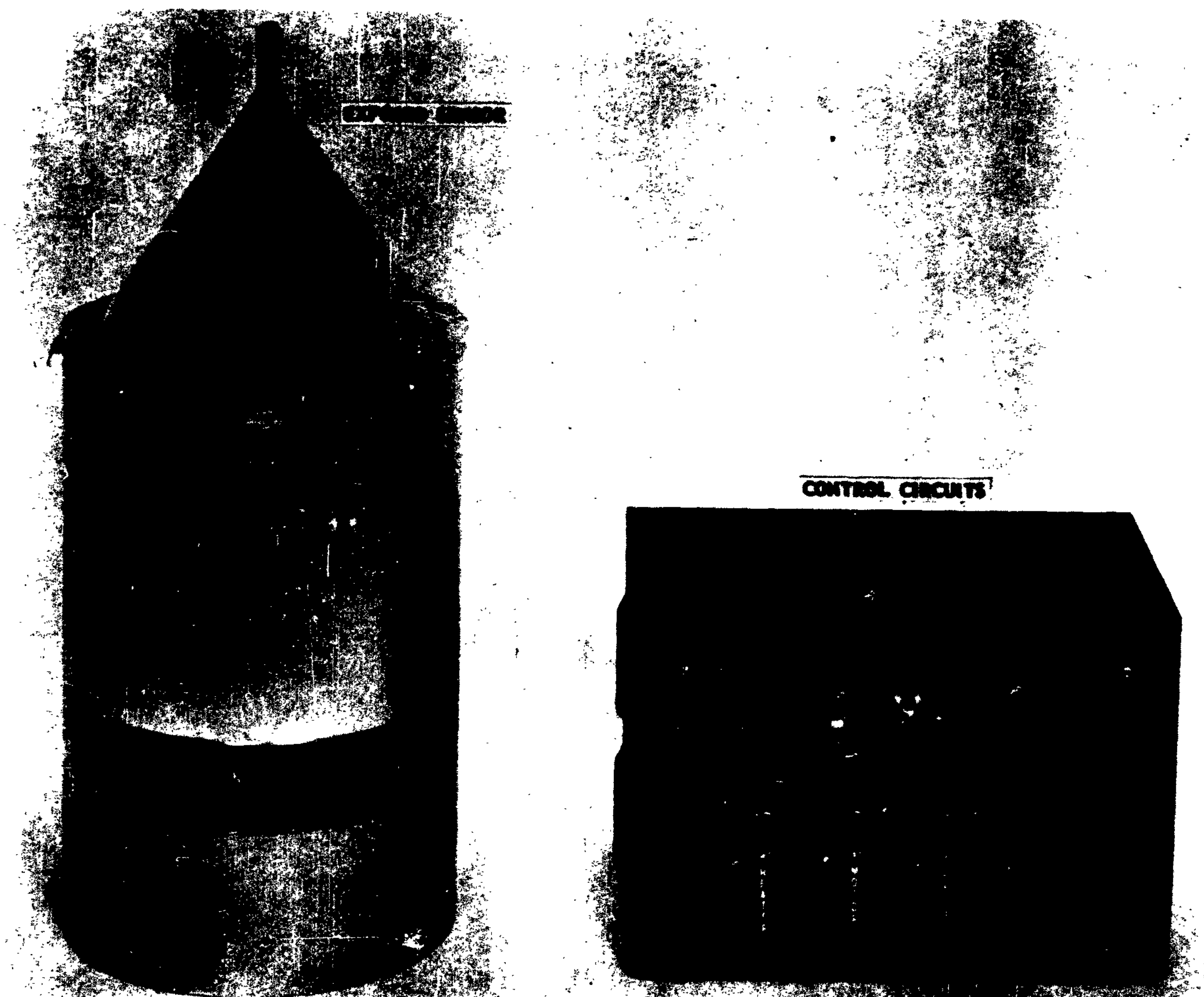



FIG. 14 PRECIPITATION INDICATOR AND CONTROL CABINET

8. Visual Distance Computer

This system was a developmental model and was not utilized by the project (Figs. 5, 10 and 12).

9. Master Timing System

A multi-timer transmitted 5-minute pulses to all recorders to provide a synchronized time basis for data analyses.

10. Communications

The two project vehicles were equipped with ground control communication facilities to permit access to the airfield at all times. This was an essential feature since data acquisition and maintenance was required at all hours. For fixed communications, receiving facilities were available on VHF and UHF. Tape recorders furnished the ability to repeat pilot reports which might otherwise have been lost due to interference or inaudibility. The Communications Console is shown in Fig. 12; other receiver facilities are shown in Fig. 5.

11. Data Reduction Devices

A film reader permitted detailed analysis of film data obtained from the rotating-beam ceilometer and radar cameras. A semiautomatic oscillogram amplitude tabulator was used to reduce all data from strip charts, particularly for the variation of transmittance studies.

12. Operations Recorder

The 20-pen unit (Fig. 5) recorded the following operations: master timing pulses, radar camera pulses, approach light intensity settings, runway light intensity settings, electronic flashing approach light system operation, rotating-beam ceilometer camera operation, occurrence of precipitation, and day/night indication.

## INVESTIGATION OF APPROACH LIGHT CONTACT HEIGHT

### Introduction

Virtually continuous efforts for the past decade under the sponsorship of the Federal Aviation Agency, Air Navigation Development Board, Airways Modernization Board, Air Force Cambridge Research Center, and the U. S. Weather Bureau have resulted in a system designed to quantitatively describe approach visibility conditions to pilots. It was anticipated that the nature of the system may facilitate more direct utilization than can be derived from conventional aviation weather measurements of ceiling and visibility. Referencet 1 through 5 describe the most prominent phases of development .n this area of approach visibility research.

The product of these efforts has been termed approach light contact height (ALCH). Figure 15 illustrates the elementary geometrical relationship of ALCH to slant-range and the approach light system.

ALCH is defined as the height above the plane of the runway at which a pilot making an Instrument Landing System (ILS) or Ground Controlled Approach (GCA) can expect to see at least a 500-foot segment of the approach light system, with certain probabilities. It is a means of describing the vertical component of slant-range, a vital flight factor required by a pilot for a successful landing during low cloud and visibility conditions. Accurate ALCH measurements can provide to the pilot information of the altitude at which he can change from instrument to visual methods of flight techniques. He can be apprised of the likelihood of making visual contact with the approach lights prior to descending to the published legal minimum altitude. Properly measured and furnished in a timely manner with respect to the final approach of the aircraft, ALCH can impart to the pilot greater confidence during the critical stages of his descent, with resulting increased operational safety and decreased frequency of missed approaches.

Presently there is no acceptable instrumental capability of directly measuring ALCH. The system described in this report was developed to utilize readily available surface weather observation instrumentation: transmissometer; rotating-beam ceilometer; and day/night switch. The information provided by the sensors, coupled with the luminous intensity of the light target, established the empirical basis for a solution to the ALCH problem.

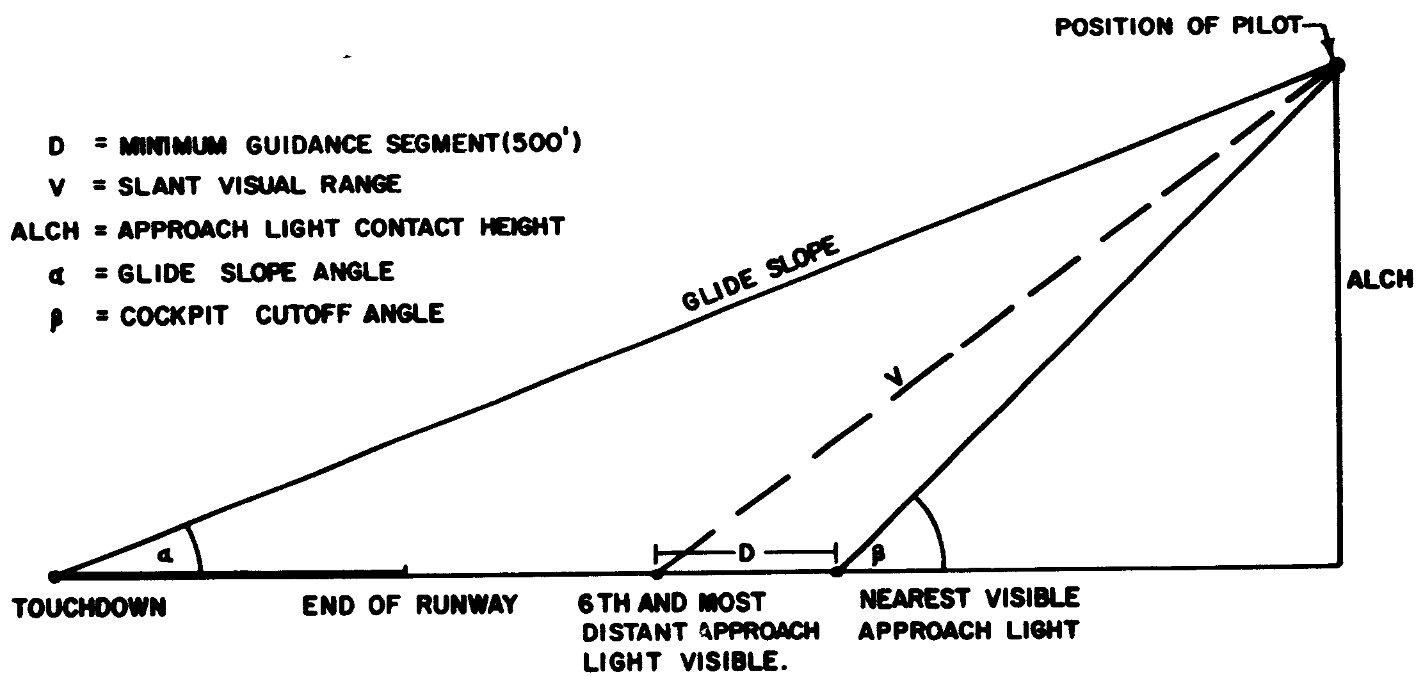



FIG. 15 GEOMETRY OF APPROACH

In this current phase, as in the Newark development period (Reference 1), the ALCH concept specifies the 20 per cent and 90 per cent levels of probability. These probabilities can be described as the altitudes by which 20 per cent of a representative group of pilots will have visual contact with the high intensity approach lights, and a lower altitude by which a larger group, 90 per cent of the pilots, will have visual contact with the light target.

The selection of the 20 per cent and 90 per cent levels of probability is to some extent arbitrary. However, operational experience and extensive discussions with pilots have indicated a favorable acceptance. A wider range of values would tend to be too inclusive, providing too gross a measure by which a pilot can determine the validity to him of the ALCH values disseminated under instrument landing conditions. Conversely, a narrower range would restrict the effective application of ALCH techniques to a relatively small pilot sample, and provide little aid to the general pilot community.

There has been extensive discussion regarding the possibility of greater operational acceptance and understanding of the ALCH concept were only one probability value disseminated, as in the case of runway visual range (RVR). Selection of the 50 per cent level, for example, could require less mental assimilation by an already overburdened pilot, than a bracket of altitudes. However, two probabilities impart a more complete description of the weather conditions to be encountered, avoid possible confusion with other reported weather parameters such as ceiling, and can find ready recognition by pilots following a period of operational familiarization.

## Background

Between May 1, 1957, and March 31, 1959, an extensive data acquisition and evaluation program was conducted at Newark, New Jersey, Airport. As a result of these efforts, an empirical system of ALCH was developed, refined, and simplified to a point at which the system was considered capable of operational utilization. From May 1957 until June 1961, ALCH was, in fact, a test operational program at Newark Airport (Reference 1).

To determine if the ALCH methods and constants empirically derived from data collected during low ceiling and visibility conditions at Newark apply to other locations, lighting systems, and aircraft types, a program of pilot reports of approach and runway light sightings was conducted at NAFEC. Data collection, reduction, and

analysis were designed to replicate the comparable effort at Newark, reported in considerable detail in Reference 1. The design of the Atlantic City project included precautions to eliminate technical or other influences which might have created a disparity between the data sample acquired at Atlantic City and the information developed at Newark. Considerable attention was devoted to all areas of data acquisition, analysis techniques, and instrumentation to provide an element of data continuity.

Data Acquisition

The basic data collection program was designed to parallel that at Newark. The details, however, were enlarged to permit application to additional task assignments.

When a weather condition with cloud heights of 800 feet or less and/or visibilities of 1-1/2 miles or less was forecast for a 2-hour or longer duration during the succeeding 24-hour period, support services were requested in the form of aircraft, pilots, and experimental air traffic control personnel. At the materialization of the anticipated low flying weather, all assigned personnel reported for duty and aircraft were launched. Pilots previously had been briefed extensively on the manner of reporting navigational fixes and significant visual contacts.

Aircraft were required to execute a straight-in ILS approach to instrument runway 13. The pilot reported passing the outer marker inbound to alert the project meteorologist and to initiate instrumentation operation. His next reports were of approach and runway light contacts in a phraseology specified in the earlier briefings. Throughout the approach all necessary radio frequencies were monitored by the project meteorologist.

At the moment of the pilot's report of visual contact, a relay system was actuated which photographed the GCA MPN-11 radar elevation and azimuth oscilloscopes, triggered marking pens on all recorders, and cued the film record within the ceilometer camera. Concurrently, the meteorologist recorded pertinent data regarding the approach and runway light intensities, time of visual contact, and the oral report and comments of the pilot. Data for every approach were entered on a sorting system data card. Following each period of data acquisition all instrument records were reduced and information entered on the data cards. The parameters used in the analysis of ALCH were determined for the instant of the pilot's reported contact with the lights.

Parameters Measured

The basic parameters derived for each report of light targets, and used throughout this and succeeding analyses, are:

Cloud Height ($\overline{H}_c$): The average, to the nearest foot, of four consecutive measurements made by the middle marker RBC occurring immediately prior to the pilot's report.

Transmittance ($T_{500}$): Percentage of transmission of light across a distance of 500 feet at the time of pilot report. T2 was used in ALCH analysis.

Illumination ($E_g$): For the basic ALCH concept, the ambient illuminance determined in two categories (day and night) by a single day/night switch. Additional analyses required the quantitative value of illuminance on a horizontal surface as sensed by the terrain illuminometer.

Aircraft height at approach light contact ($H_{AR}$): The height, to the nearest foot, of the aircraft above the ground determined from the GCA radar photograph made at the time of the pilot's report.

Approach light setting (LS): The intensity of the approach lights, using index numbers 1 through 5, at the time of approach light contact. The photometric characteristics of these lights are shown in Table I.

Precipitation: A yes/no indication of precipitation occurring along the approach path was obtained from an indicator located at the middle marker site. If precipitation was indicated 2-1/2 minutes prior to or following an approach, it was assumed that precipitation was representative of the pilot's environment.

Other parameters recorded included aircraft type, runway light intensity setting, electronic flashing approach light system (EFAS) on or off, NAFEC experimental light configurations as applicable, times of light contacts, pilot's oral cue, aircraft deviation from centerline, and range from touchdown at the instant of light contact. Each test approach was identified by a data acquisition period number and approach number.

Summary of Data Acquired

During the 18-month period of data collection, from December 1959 through May 1961, a total of 801 approaches were monitored

TABLE I

COMPARISON OF LIGHT SETTINGS AND INTENSITIES FOR ATLANTIC CITY AND NEWARK APPROACH LIGHT SYSTEMS

## NEWARK

Electronic flashing approach light system (EFAS):
Sylvania Type X7040NF lamp assembly, Xenon filled lamps R4336
2 flashes per second per lamp with a flash duration of about 1/5000 of a second (200-250 microseconds)
Instantaneous peak intensity: 30 million candlepower
Effective beam intensity: 10-15 thousand candlepower

Approach Light Type: 300 PAR 56 (300W, 25V)

| Light Setting | Factor | Maximum Intensity Candlepower | Representative Intensity Candlepower |
|---|---|---|---|
| 5 | 1.00 | 29,000 | 15,000 |
| 4 | .20 | 5800 | 3000 |
| 3 | .04 | 1160 | 600 |
| 2 | .008 | 232 | 120 |
| 1 | .0016 | 46 | 24 |

## ATLANTIC CITY

Electronic flashing approach light system (EFAS):
Sylvania Type CD-2000 lamp assembly, Xenon filled lamps R4336
2 flashes per second per lamp with a flash duration of about 1/5000 of a second (200-250 microseconds)
Instantaneous peak intensity: 30 million candlepower
Effective beam intensity: 10-15 thousand candlepower

Approach Light Type: 20A/PAR 56 (300W, 15V)

| Light Setting | Factor | Maximum Intensity Candlepower | Representative Intensity Candlepower |
|---|---|---|---|
| 5 | 1.00 | 29,000 | 15,000 |
| 4 | .25 | 7250 | 3750 |
| 3 | .045 | 1305 | 675 |
| 2 | .012 | 348 | 180 |
| 1 | .0025 | 73 | 38 |

Configurations at Newark and Atlantic City are National Standard (A) as outlined in Reference 6

under test flight conditions. Of these, 595 (74 per cent) were available for general analysis, and 559 (70 per cent) available specifically for ALCH analysis. These percentages compare favorably with the Newark study where only 52 per cent of approaches monitored were available for ALCH analysis. Total usable flights at Newark exceeded the current study because of the considerably larger gross numbers. The distribution of valid data collected by weather category and illumination class at Newark compared to similar data at Atlantic City is listed in Table II. Table III lists the distribution of pilot reports by aircraft type.

Most of the test flights not considered fully valid for ALCH analysis were those accomplished when cloud heights and atmospheric transmittances were just above those limits established for data acquisition. These flights were to insure that the upper range of the data spectrum was adequately sampled. The spectrum of acquired valid data is shown in Figs. 16 and 17. Other approaches could not be considered valid because of incoherent communications, EFAS interference with the RBC indication, no pilot report, incorrect pilot report, or equipment malfunction.

No stipulation of pilot or aircraft could be made by the project meteorologist since selection of a pilot was dependent upon available manpower and pilot qualifications for the type of weather anticipated. Similarly, the selection of a test aircraft depended on prior use by other tasks, maintenance, and suitability of the aircraft for the type of weather which might be encountered.

Acting on the Newark precedent, it was stipulated that data acquisition would take place when cloud bases were 800 feet or less and/or the presence of transmittance for a 500-foot baseline equal to or less than 0.83 day or 0.73 night (1-1/2 miles meteorological visibility). For purposes of analysis, the data were further stratified into three basic categories:

Low clouds: $\overline{H}_c \leq 800$ feet, day or night.

Homogeneous surface-based obstruction to vision with the exception of snow (HF): $T_{500} \leq 0.83$ day, 0.73 night. When low clouds were present below 800 feet, HF was considered the significant data category if, when tested by Allard's Law, a pilot's slant visual range was more restricted by atmospheric transmission than by cloud layers.

TABLE II

DISTRIBUTION OF VALID DATA ACQUIRED AT NEWARK AND ATLANTIC CITY

| Weather Category | Illumination Class | Newark No. of Reports | Newark Per cent of Total | Atlantic City No. of Reports | Atlantic City Per cent of Total |
|---|---|---|---|---|---|
| Low clouds | Day | 839 | 35 | 307 | 55 |
| Low clouds | Night | 975 | 41 | 202 | 36 |
| Total low clouds | | 1814 | 76 | 509 | 91 |
| HF (Fog, smoke, and haze) | Day | 314 | 13 | 9 | 2 |
| HF (Fog, smoke, and haze) | Night | 61 | 3 | 39 | 7 |
| Total HF | | 375 | 16 | 48 | 9 |
| Snow | Day | 86 | 4 | 2 | 0 |
| Snow | Night | 100 | 4 | 0 | 0 |
| Total snow | | 186 | 8 | 2 | 0 |
| Total valid reports | | 2375 | 100 | 559 | 100 |

TABLE III

DISTRIBUTION OF PILOT REPORTS BY AIRCRAFT TYPE

| Aircraft Type | Low Clouds Day | Low Clouds Night | HF Day | HF Night | SNOW Day | SNOW Night | Total |
|---|---|---|---|---|---|---|---|
| Aero Commander | 123 | 93 | 1 | 7 | | | 224 |
| Martin 202 | 1 | | | | | | 1 |
| DC-3 | 35 | 21 | | 4 | | | 60 |
| DC-4 | 29 | 5 | | | 2 | | 36 |
| Convair | 71 | 72 | 7 | 28 | | | 178 |
| Martin 404 | 1 | 2 | | | | | 3 |
| Gulfstream | 13 | 2 | | | | | 15 |
| Beechcraft (C-45) | 1 | | | | | | 1 |
| Albatross (SA-16) | 26 | 5 | 1 | | | | 32 |
| Jet (F9F) | 6 | | | | | | 6 |
| Other | 1 | 2 | | | | | 3 |
| Total | 307 | 202 | 9 | 39 | 2 | | 559 |

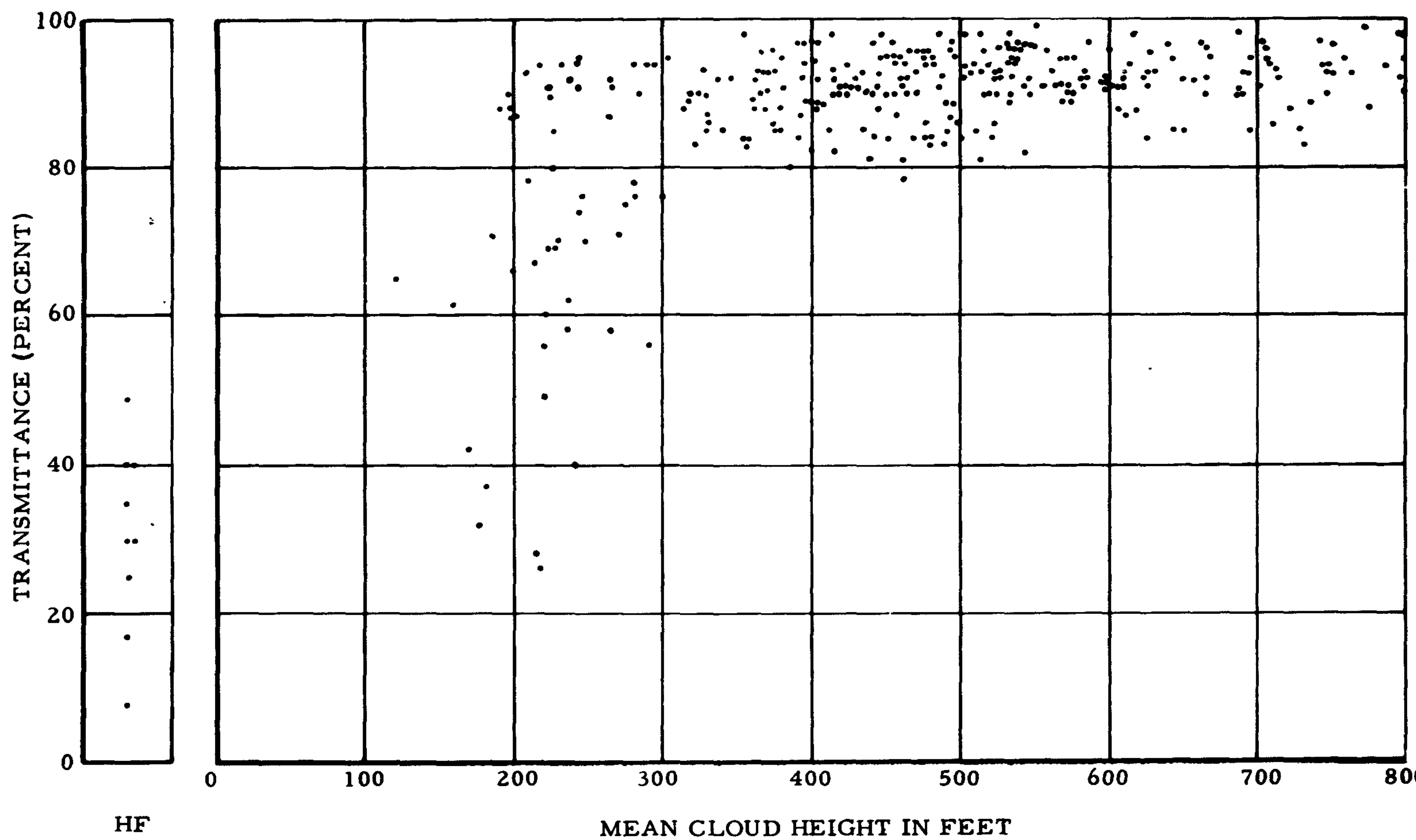



FIG. 16 SPECTRUM OF DATA COLLECTION - DAY - 316 CASES

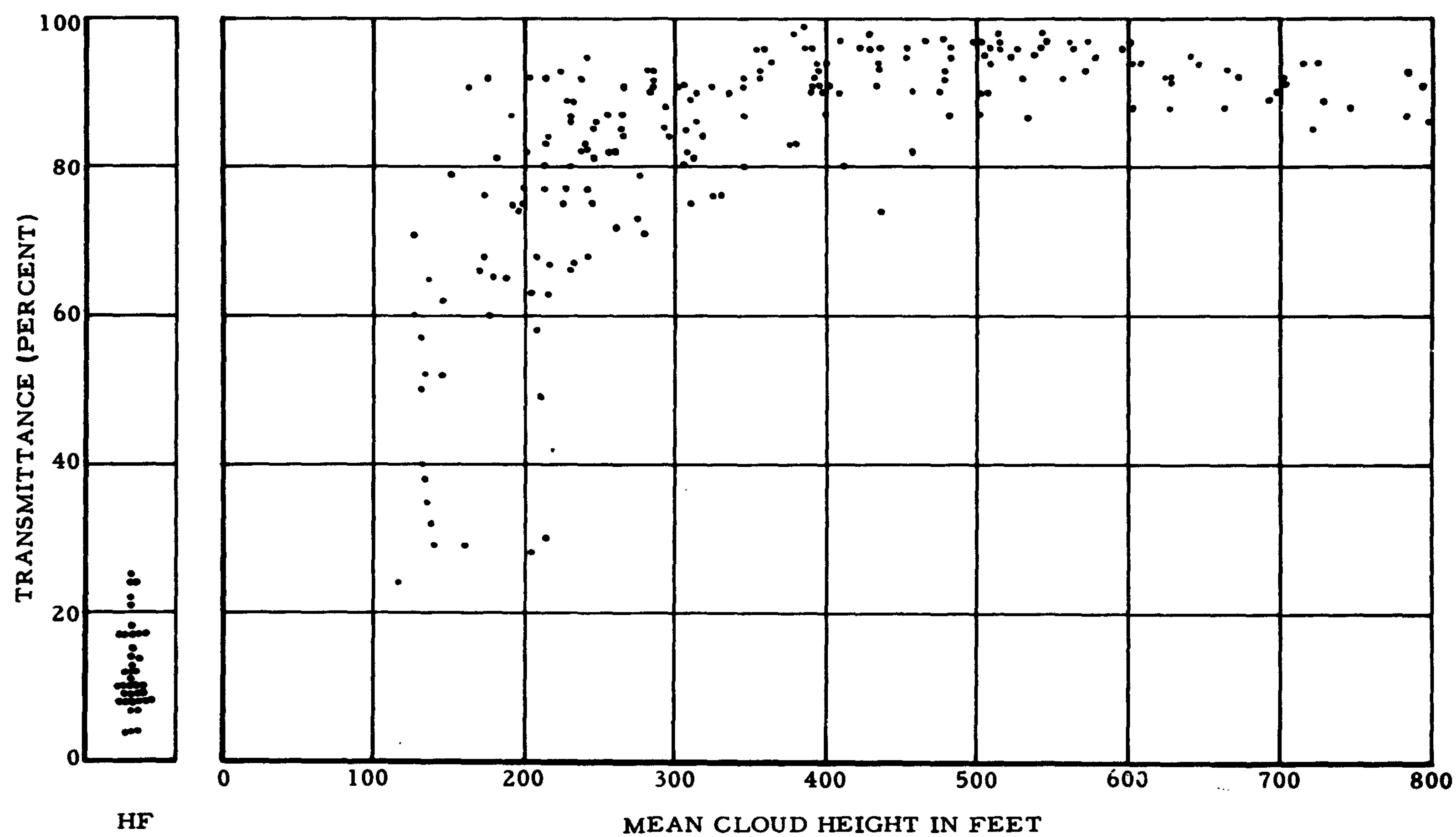



FIG. 17 SPECTRUM OF DATA COLLECTION - NIGHT - 241 CASES

Snow: $T_{500} \leq 0.83$ day, 0.73 night. Snow was considered the significant data category when it was determined to be the dominant obstruction to vision.

In addition to the information in Table II and Figs. 16 and 17, a further breakdown of low clouds by $\overline{H}_c$ and $T_{500}$ is listed in Table IV.

Statistical Validity of Data Sample Size

Considering the Newark sample size, a question to be resolved was the sample size required at Atlantic City to assure a statistically valid comparison with the Newark data. The Atlantic City sample size had to be sufficiently large to avoid unreliable or inaccurate determinations, but not of inordinate size which could have been practically and economically unsound.

This estimate of the minimum sample size was obtained by making a reasonable assumption that the population at Atlantic City would be substantially the same as that from which the Newark data were sampled. It was also established that $\pm 25$ feet in ALCH was the allowable difference between the sample mean and population mean. Confidence limits were set at 95 per cent that the error would not exceed $\pm 25$ feet. Having established the limits of error and confidence, the sample size required to estimate with desired precision could be determined from the equations:

$$N = \left| (Z_{1-a/2}) \left(\frac{\sigma}{d}\right) \right|^2 \quad \text{where } Z_{1-a/2} = 1.96 = 2 \text{ (approx.)} \qquad (1)$$

$$N \approx \left(\frac{2\sigma}{d}\right)^2 \qquad (2)$$

$$N \approx \frac{4\sigma^2}{d^2} \qquad (3)$$

where N = estimate of required sample size,

Z = the normal deviate (here, at a 95 per cent confidence limit),

d = the maximum allowable difference between the sample mean and population mean (here, an allowable error of $\pm 25$ feet in ALCH),

$\sigma$ = estimate of the population standard deviation.

TABLE IV

DISTRIBUTION OF LOW CLOUD DATA
BY CLASSES OF $\overline{H}_c$ AND $T_{500}$

Cloud Height In Feet - Day

$\overline{H}_c$

| $T_{500}$ Per Cent | 1 To 100 | 101 To 200 | 201 To 300 | 301 To 400 | 401 To 500 | 501 To 600 | 601 To 700 | 701 To 800 | Totals Instances |
|---|---|---|---|---|---|---|---|---|---|
| 01-10 | - | - | - | - | - | - | - | - | - |
| 11-20 | - | - | - | - | - | - | - | - | - |
| 21-30 | - | - | 2 | - | - | - | - | - | 2 |
| 31-40 | - | 3 | 1 | - | - | - | - | - | 4 |
| 41-50 | - | 1 | 1 | - | - | - | - | - | 2 |
| 51-60 | - | - | 5 | - | - | - | - | - | 5 |
| 61-70 | - | 3 | 6 | - | - | - | - | - | 9 |
| 71-80 | - | 1 | 9 | 1 | 1 | - | - | - | 12 |
| 81-90 | - | 4 | 5 | 26 | 32 | 16 | 11 | 9 | 103 |
| 91-99 | - | - | 13 | 20 | 42 | 51 | 24 | 20 | 170 |
| Totals | - | 12 | 42 | 47 | 75 | 67 | 35 | 29 | 307 |

Cloud Height In Feet - Night

$\overline{H}_c$

| $T_{500}$ Per Cent | 1 To 100 | 101 To 200 | 201 To 300 | 301 To 400 | 401 To 500 | 501 To 600 | 601 To 700 | 701 To 800 | Totals Instances |
|---|---|---|---|---|---|---|---|---|---|
| 01-10 | - | - | - | - | - | - | - | - | - |
| 11-20 | - | - | - | - | - | - | - | - | - |
| 21-30 | - | 3 | 2 | - | - | - | - | - | 5 |
| 31-40 | - | 4 | - | - | - | - | - | - | 4 |
| 41-50 | - | 1 | 1 | - | - | - | - | - | 2 |
| 51-60 | - | 6 | 1 | - | - | - | - | - | 7 |
| 61-70 | - | 6 | 7 | - | - | - | - | - | 13 |
| 71-80 | - | 7 | 11 | 5 | 2 | - | - | - | 25 |
| 81-90 | - | 2 | 23 | 14 | 5 | 4 | 5 | 5 | 58 |
| 91-99 | - | 2 | 9 | 20 | 20 | 21 | 10 | 6 | 88 |
| Totals | - | 31 | 54 | 39 | 27 | 25 | 15 | 11 | 202 |

It was also possible to determine if the initial sample size at Newark was sufficiently large to estimate $\sigma^2$. With a 95 per cent confidence limit it was determined that the required sample size at Newark for a correct estimate of $\sigma^2$ was about 751 test flight approaches. This requirement was satisfied only for the low-cloud categories.

The concluding calculations were then made:

| Low clouds, night, Newark, 975 reports | Low clouds, day, Newark, 839 reports |
|---|---|
| $\sigma_x = 153.5$ | $\sigma_x = 160.6$ |
| $\sigma_y = 126.6$ | $\sigma_y = 134.0$ |

where $x = \overline{H}_c$

$y = H_{AR}$

Let $\sigma_{max} = \sigma_x = 160.6$

and $N_{max} = \frac{4\sigma^2_{max}}{d^2} = 165$ approaches.

Therefore, a minimum of about 165 approaches was required at Atlantic City for low-cloud categories to adequately relate the comparable Newark data. This requirement was satisfied.

The number of HF and snow cases at Newark were considered too small a sample of the population for an absolute determination of a final ALCH system. While the sample size at Atlantic City was insufficient for a fully valid statistical comparison with the HF Newark data, certain logical comparisons could be made. The number of snow data acquired at Atlantic City was insignificant.

Evaluation of ALCH, Low-Cloud Category

1. Background

The concept of ALCH assumes that the atmospheric

transmission is uniform between the aircraft and the ground, and that the measurement made by the surface-based transmissometer can be applied as representative of this idealized homogeneous state. Although this assumption has not been fully tested due to the limited state of the art in suitable instrumentation, the hypothesis is of sufficient substance to permit a system of ALCH to be predicated on Allard's Law. However, this assumption cannot be sustained in the presence of low clouds, nor can any surface-based measurement be considered representative of a non-homogeneous state. Under conditions of low clouds, ALCH is based on empirically derived linear regression equations in which the independent variable is the mean cloud height, $\overline{H}_c$.

To critically examine the ALCH curves, empirically determined at Newark, it was necessary to establish that the data sample at Atlantic City reacted substantially the same as the Newark sample, when subjected to the same analytical procedures. If the reaction was similar, it could then be assumed that the technical characteristics of the Atlantic City data typified the Newark data, and valid conclusions could be made regarding the comparison of the test results.

2. Linear Partial Correlation Analyses

Atlantic City data were examined using the technique of linear partial correlations following the same methods and tests of significance as had been employed at Newark. The analyses of the results (Table V) stated below are substantially the same as the Newark results. It was considered a valid approach, therefore, to base an evaluation of ALCH methods derived at Newark on the Atlantic City data sample.

a. The correlations between $H_{AR}$ and $\overline{H}_c$, and $T_B$ and $\overline{H}_c$ are the most significant. The correlations between $H_{AR}$ and $T_B$, $T_B$ and LS reveal a marked decrease in significance when the final partial correlations at Newark are compared to the final partial correlations at Atlantic City. This latter characteristic can be attributed to the differences in transmissometer baselines between the two test stations. (See footnote, Table V.)

b. The relationships between $T_B$, LS, and $\overline{H}_c$ indicate visibility is the primary factor used by control tower personnel in determining approach light intensity at night. There are some indications that consideration is given to cloud height during the day at Atlantic City.

TABLE V

CORRELATION AND PARTIAL CORRELATION COEFFICIENTS OF LOW-CLOUD CATEGORY AT NEWARK AND ATLANTIC CITY

| | Day | | Night | |
|---|---|---|---|---|
| Variables | Newark 839 cases | Atlantic City 307 cases | Newark 975 cases | Atlantic City 202 cases |
| *$H_{AR}\ T_B$ | 0.54 | 0.39 | 0.52 | 0.52 |
| *$H_{AR}\ T_B \cdot \overline{H}_c$ | 0.33 | 0.10 | 0.26 | 0.07 |
| *$H_{AR}\ T_B \cdot LS$ | 0.55 | 0.37 | 0.50 | 0.49 |
| *$H_{AR}\ T_B \cdot E_g$ | 0.55 | 0.42 | - | - |
| *$H_{AR}\ T_B \cdot \overline{H}_c\ LS$ | 0.36 | 0.11 | 0.25 | 0.06 |
| *$H_{AR}\ T_B \cdot \overline{H}_c\ E_g$ | 0.35 | 0.12 | - | - |
| *$H_{AR}\ T_B \cdot LS\ E_g$ | 0.56 | 0.40 | - | - |
| *$H_{AR}\ T_B \cdot \overline{H}_c\ LS\ E_g$ | 0.37 | 0.13 | - | - |
| $H_{AR}\ \overline{H}_c$ | 0.66 | 0.64 | 0.66 | 0.79 |
| $H_{AR}\ \overline{H}_c \cdot T_B$ | 0.54 | 0.56 | 0.53 | 0.70 |
| $H_{AR}\ \overline{H}_c \cdot LS$ | 0.65 | 0.65 | 0.65 | 0.78 |
| $H_{AR}\ \overline{H}_c \cdot E_g$ | 0.66 | 0.64 | - | - |
| $H_{AR}\ \overline{H}_c \cdot T_B\ LS$ | 0.54 | 0.56 | 0.53 | 0.71 |
| $H_{AR}\ \overline{H}_c \cdot T_B\ E_g$ | 0.54 | 0.54 | - | - |
| $H_{AR}\ \overline{H}_c \cdot LS\ E_g$ | 0.66 | 0.63 | - | - |
| $H_{AR}\ \overline{H}_c \cdot T_B\ LS\ E_g$ | 0.54 | 0.55 | - | - |
| $H_{AR}\ LS$ | -0.13 | -0.14 | -0.19 | -0.20 |
| $H_{AR}\ LS.\ T_B\ \overline{H}_c$ | 0.15 | 0.08 | 0.02 | -0.04 |
| $H_{AR}\ LS.\ T_B\ \overline{H}_c\ E_g$ | 0.14 | 0.07 | - | - |
| $H_{AR}\ E_g$ | -0.12 | -0.01 | - | -- |
| $H_{AR}\ E_g.\ T\ \ \overline{H}_c\ LS$ | -0.17 | -0.07 | - | -- |
| *$T_B\ \overline{H}_c$ | 0.50 | 0.51 | 0.54 | 0.61 |
| *$T_B\ \overline{H}_c.\ E_g$ | 0.50 | 0.53 | - | - |
| *$T_B\ LS$ | -0.45 | -0.31 | -0.41 | -0.35 |
| *$T_B\ LS.\ \overline{H}_c$ | -0.42 | -0.19 | -0.37 | -0.29 |
| *$T_B\ LS.\ E_g$ | -0.45 | -0.25 | - | - |
| *$T_B\ LS.\ \overline{H}_c\ E_g$ | -0.42 | -0.12 | - | - |
| *$T_B\ E_g$ | 0.07 | 0.35 | - | - |
| *$T_B\ E_g.\ \overline{H}_c$ | 0.10 | 0.38 | - | - |
| $LS\ E_g$ | -0.11 | -0.22 | - | - |
| $LS\ E_g.\ T_B\ \overline{H}_c$ | -0.08 | -0.16 | - | - |
| $\overline{H}_c\ LS$ | -0.19 | -0.29 | -0.19 | -0.20 |
| $\overline{H}_c\ LS.\ T_B$ | 0.04 | -0.16 | 0.04 | 0.01 |
| $\overline{H}_c\ LS.\ T_B\ E_g$ | -0.04 | -0.19 | - | - |
| $\overline{H}_c\ E_g$ | -0.02 | 0.04 | - | - |

*The transmissometer baseline at Atlantic City was 500 feet and at Newark 810 feet. Linear analysis which employs transmittance is valid for the given transmissometer baseline only. This should be considered when quantitatively comparing Newark correlation coefficients with those obtained at Atlantic City, where $T_B$ is one of the two variables involved in the initial correlation. Qualitative comparisons of degree of correlation and significance however, are valid.

c. $H_{AR}$ correlates best with $\overline{H}_c$. This is the largest and most significant of all correlations involving aircraft height.

d. The large total correlations between $H_{AR}$ and $T_B$ are deceiving when viewed by themselves. When the effect of $\overline{H}_c$ is removed, the total correlations show a sharp decrease for both airports under day and night conditions. A better understanding of the degree of influence $T_B$ has on $H_{AR}$ may be obtained by viewing the order of magnitude of the decrease in the total correlation between $H_{AR}$ and $\overline{H}_c$ when the effect of $T_B$ is removed.

e. In every instance where $E_g$ is held constant there is practically no difference between the partial correlation coefficients and the basic correlations. Illumination appears to be the least significant of all the variables involved.

f. The low order of magnitude of the final correlation coefficients involving $H_{AR}$ and LS results in some doubt as to whether the steady burning approach lights significantly aid the pilot in establishing initial light contact with the approach light array in the presence of the EFAS. This analysis was corroborated by the Atlantic City experience where initial contact with the approach lights was almost always based on the EFAS regardless of the intensity of the steady burning lights.

g. For a linear analysis only, at Atlantic City and Newark, partial correlation indicates the variables should be rated in order of decreasing importance as follows: $\overline{H}_c$; $T_B$; LS; $E_g$.

3. Effect of Low Visibilities in the ALCH Concept

As at Newark, the linear correlations at Atlantic City revealed a consistently high correlation and significant relationship between $H_{AR}$ and $\overline{H}_c$, with a secondary maximum for $H_{AR}$ and $T_B$. In addition, it has been established that low visibilities usually accompany low cloud heights (Table IV, Figs. 16 and 17, and Reference 1). There are occasions when low visibility conditions accompany clouds below 800 feet, but the clouds are still relatively high. These conditions might result in excessively high ALCH values if the system were based exclusively on a low-cloud concept. A Newark technique was successfully utilized to resolve the few cases which occurred at Atlantic City. When low visibilities accompanied low clouds, ALCH was determined using the HF and low-cloud concepts. The lower of the two values thus derived was considered in force, and disseminated.

The moderate correlation between transmittance and approach light intensity setting indicated that, at Atlantic City and Newark,

visibility was a prime factor used by control tower personnel in establishing the approach light environment. This is as expected in view of the official guidance given the tower specialists, which predicates lighting configuration almost exclusively on visibility (see paragraph 4, following).

Contrary to the earlier assumptions at Newark, it since has been rationalized that the intensities of the steady burning approach lights were of subsidiary importance to the EFAS in the empirical development and subsequent validity of ALCH. This was true in both HF and low-cloud categories. This reasoning has been based on the requirements of the official approach light intensity guide, and the knowledgeable tendencies of tower specialists to overdrive the lights as a safety precaution, which results in the EFAS almost invariably operating during conditions of low ceilings and visibilities.

A review of the Newark data was conducted to justify this rationale. It was revealed that the EFAS was the most dominant light target available to the pilot at the time of his approach during 95 per cent of all day test flights, and 80 per cent of all night test flights. At Atlantic City the EFAS was the most dominant light target available during 100 per cent of all day test approaches and 94 per cent of all night test approaches. During all test periods at Atlantic City and Newark, the approach light systems were operated in accordance with established routine. It was then a logical inference that, unless otherwise defined by the pilot's oral cue, his report of approach light contact was based on recognition of the most dominant light target available in the approach light array.

Operation guides and performance experience have indicated that the EFAS would usually be operating under conditions which would require ALCH to be disseminated, and invariably on during the poorest weather conditions when the need for ALCH would be greatest. Since the effective intensity of the EFAS approximates that of the high-intensity, steady burning approach lights at maximum representative intensity, and because of the eye-catching sequenced flashing configuration, it is likely that the EFAS would serve as the ALCH light target, as it has during the test programs, for the bulk of approaches made under weather conditions when ALCH would be required.

4. Official Approach Light Intensity Guide (abstracted from FAA ATS Manual 1-A, 8/1/61)

High-Intensity Approach Lights

The high-intensity approach lights shall be operated in the following manner:

a. Lighted at any time of day or night when instrument approaches are being conducted, at any time a pilot so requests, and at other times when the controller deems it advisable.

b. Operated in conformance with the general guide as shown in the following table:

| Relative Brightness | | Visibility Conditions | |
|---|---|---|---|
| Step | Per Cent | Day | Night |
| 1 | 0.16 | - - - | 2 miles or better |
| 2 | 0.80 | - - - | 1 mile to 2 miles |
| 3 | 4 | 2 miles to CAVU | 1/4 mile to 1 mile |
| 4 | 20 | 1 mile to 2 miles | Pilot's request |
| 5 | 100 | 1/4 mile to 1 mile | Pilot's request |

(1) The table of brightness settings is for use with white lights. Experience may show that red lights should be burned one step brighter. Brightness settings may be varied during the daytime according to whether the day is light or dark, and at night according to the amount of extraneous lighting of buildings and highways. Individual approach light configurations and locations may require different settings.

(2) During periods of no traffic, the lights should be turned off and the lights need not be on during the conduct of practice instrument approaches.

(3) ICAO procedures governing operation of high-intensity approach lights require the corresponding runway lights to be lighted whenever the approach lights are lighted. This requirement should be observed when practicable; however, controllers may deviate from this rule, in order that approach lights may be left on for use of an approaching aircraft, while some other aircraft is using the runway lights on a runway not served by the approach lights.

(4) Sequenced flashing lights associated with approach light systems are used for additional identification purposes. They

will not be operated unless the approach lights are also in operation. The flashers with approach lights will be operated as follows:

Daytime

When the visibility without regard to ceiling is 3 miles or less at the approach end of the runway where installed, or on pilot's request.

During Hours of Darkness

When the ceiling is 500 feet or less and/or visibility is 1 mile or less, or on pilot's request.

In addition to the above, the flashers with approach lights may be operated in conditions above the values prescribed, when in the opinion of the tower specialist, the use of such lights will be helpful in the completion of the approach.

## 5. Effect of Rain on Low-Cloud Determination of ALCH

ALCH values have been based on a pattern of data which combined test approaches made during periods with and without precipitation. Table VI lists the distribution of aircraft heights under all low-cloud category conditions at Atlantic City. Table VII lists the distribution of aircraft height scored on the same basis as Table VI, but excluding all approaches made during periods of rain.

At Newark there was considerable similarity of distribution between "rain" and "no rain" cases. The explanation was made regarding this similarity, that many test approaches were invalidated because the radar that was used to determine $H_{AR}$ failed to discriminate against precipitation during periods of moderate and heavy rain. The similarity of distribution observed at Newark may be attributed to inefficient sampling.

This conjecture is justified by the comparable Atlantic City data. Here, virtually no approaches were invalidated due to excessive precipitation echoes on the radar. Table VIII is a compilation of the data of Tables VI and VII indicating that the ALCH low-cloud category values are conservative with respect to approaches with rain, and effectively accommodates the combined "rain" and "no rain" cases when scored on the basis of the Atlantic City regression equations. Therefore, there is insufficient justification to require the complexities of separate ALCH considerations for the occurrence or nonoccurrence of rain.

## TABLE VI

### DISTRIBUTION OF AIRCRAFT HEIGHTS
### LOW CLOUD DATA, LINEAR ANALYSIS

| | NIGHT | | | DAY | | |
|---|---|---|---|---|---|---|
| p | Total No. Of Approaches | Per Cent | $\bar{H}_c$ Class | Total No. Of Approaches | Per Cent | p |
| | 2 | 6.5 | | 1 | 8.3 | |
| .2 | | | | | | .2 |
| | 29 | 93.5 | 101-200 | 11 | 91.7 | |
| .9 | | | | | | .9 |
| | 0 | 0.0 | | 0 | 0.0 | |
| | 7 | 13.0 | | 0 | 0.0 | |
| .2 | | | | | | .2 |
| | 46 | 85.2 | 201-300 | 42 | 100.0 | |
| .9 | | | | | | .9 |
| | 1 | 1.8 | | 0 | 0.0 | |
| | 4 | 10.2 | | 8 | 17.0 | |
| .2 | | | | | | .2 |
| | 34 | 87.2 | 301-400 | 39 | 83.0 | |
| .9 | | | | | | .9 |
| | 1 | 2.6 | | 0 | 0.0 | |
| | 3 | 11.1 | | 10 | 13.3 | |
| .2 | | | | | | .2 |
| | 19 | 70.4 | 401-500 | 61 | 81.4 | |
| .9 | | | | | | .9 |
| | 5 | 18.5 | | 4 | 5.3 | |
| | 4 | 16.0 | | 9 | 13.4 | |
| .2 | | | | | | .2 |
| | 20 | 80.0 | 501-600 | 54 | 80.6 | |
| .9 | | | | | | .9 |
| | 1 | 4.0 | | 4 | 6.0 | |
| | 6 | 40.0 | | 11 | 31.4 | |
| .2 | | | | | | .2 |
| | 8 | 53.3 | 601-700 | 21 | 60.0 | |
| .9 | | | | | | .9 |
| | 1 | 6.7 | | 3 | 8.6 | |
| | 1 | 9.1 | | 6 | 20.7 | |
| .2 | | | | | | .2 |
| | 7 | 63.6 | 701-800 | 20 | 69.0 | |
| .9 | | | | | | .9 |
| | 3 | 27.3 | | 3 | 10.3 | |

TABLE VII

DISTRIBUTION OF AIRCRAFT HEIGHTS
FOR NO-RAIN APPROACHES, LOW CLOUD DATA,
LINEAR ANALYSIS

| p | NIGHT Total Approaches Without Rain | NIGHT Per Cent | $\bar{H}_c$ Class | DAY Total Approaches Without Rain | DAY Per Cent | p |
|---|---|---|---|---|---|---|
| | 2 | 6.7 | | 1 | 10.0 | |
| .2 | | | | | | .2 |
| | 28 | 93.3 | 101-200 | 9 | 90.0 | |
| .9 | | | | | | .9 |
| | 0 | 0.0 | | 0 | 0.0 | |
| | 5 | 10.9 | | 0 | 0.0 | |
| .2 | | | | | | .2 |
| | 40 | 87.0 | 201-300 | 28 | 100.0 | |
| .9 | | | | | | .9 |
| | 1 | 2.2 | | 0 | 0.0 | |
| | 4 | 10.8 | | 4 | 10.8 | |
| .2 | | | | | | .2 |
| | 32 | 86.5 | 301-400 | 33 | 89.2 | |
| .9 | | | | | | .9 |
| | 1 | 2.7 | | 0 | 0.0 | |
| | 2 | 8.3 | | 8 | 12.1 | |
| .2 | | | | | | .2 |
| | 17 | 70.8 | 401-500 | 54 | 81.8 | |
| .9 | | | | | | .9 |
| | 5 | 20.8 | | 4 | 6.1 | |
| | 3 | 13.0 | | 9 | 14.1 | |
| .2 | | | | | | .2 |
| | 19 | 82.6 | 501-600 | 51 | 79.7 | |
| .9 | | | | | | .9 |
| | 1 | 4.3 | | 4 | 6.3 | |
| | 4 | 40.0 | | 5 | 20.8 | |
| .2 | | | | | | .2 |
| | 5 | 50.0 | 601-700 | 16 | 66.7 | |
| .9 | | | | | | .9 |
| | 1 | 10.0 | | 3 | 12.5 | |
| | 1 | 16.7 | | 4 | 18.2 | |
| .2 | | | | | | .2 |
| | 4 | 66.7 | 701-800 | 15 | 68.2 | |
| .9 | | | | | | .9 |
| | 1 | 16.7 | | 3 | 13.6 | |

TABLE VIII

DISTRIBUTION OF AIRCRAFT HEIGHTS
FOR RAIN AND NO-RAIN APPROACHES, LOW CLOUD DATA,
LINEAR ANALYSIS

DAY

| Total Approaches With Rain | | Total Approaches Without Rain | | Combined | | |
|---|---|---|---|---|---|---|
| No. | Per Cent | No. | Per Cent | No. | Per Cent | p |
| 14 | 25.0 | 31 | 12.4 | 45 | 14.7 | |
| | | | | | | .2 |
| 42 | 75.0 | 206 | 82.1 | 248 | 80.8 | |
| | | | | | | .9 |
| 0 | 0.0 | 14 | 5.7 | 14 | 4.6 | |

NIGHT

| Total Approaches With Rain | | Total Approaches Without Rain | | Combined | | |
|---|---|---|---|---|---|---|
| No. | Per Cent | No. | Per Cent | No. | Per Cent | p |
| 6 | 23.1 | 21 | 11.9 | 27 | 13.4 | |
| | | | | | | .2 |
| 19 | 73.1 | 145 | 82.4 | 164 | 81.2 | |
| | | | | | | .9 |
| 1 | 3.8 | 10 | 5.7 | 11 | 5.4 | |

## 6. Determination of Linear Regression Equations, ALCH, Low-Cloud Category

The linear partial correlation analysis has indicated a significant correlation exists between $H_{AR}$ and $\overline{H}_c$. This was considered an excellent basis for conducting a linear regression analysis between $H_{AR}$ and $\overline{H}_c$. Following the Newark methods, ALCH values were developed based exclusively on Atlantic City low-cloud approaches (Tables IX and X, and Fig. 18). Similar ALCH curves for Newark are shown in Fig. 19.

The regression equations derived at Atlantic City compared to the corresponding Newark equations are:

| | Atlantic City | | | Newark | |
|---|---|---|---|---|---|
| DAY | $H_{.9} = 0.452\ \overline{H}_c + 16$ | (4) | | $H_{.9} = 0.550\ \overline{H}_c - 33$ | (5) |
| | $H_{.2} = 0.452\ \overline{H}_c + 187$ | (6) | | $H_{.2} = 0.550\ \overline{H}_c + 181$ | (7) |
| | $H_{.2} - H_{.9} = 171$ feet | | | $H_{.2} - H_{.9} = 214$ feet | |
| NIGHT | $H_{.9} = 0.579\ \overline{H}_c + 30$ | (8) | | $H_{.9} = 0.548\ \overline{H}_c + 31$ | (9) |
| | $H_{.2} = 0.579\ \overline{H}_c + 192$ | (10) | | $H_{.2} = 0.548\ \overline{H}_c + 233$ | (11) |
| | $H_{.2} - H_{.9} = 162$ feet | | | $H_{.2} - H_{.9} = 202$ feet | |

Comparing the night Atlantic City and Newark data (Fig. 20) reveals an outstanding consistency in slope and range. As was expected, the range of ALCH at Atlantic City was slightly more contracted than the range at Newark. This is because the primary purpose of the test pilots at Atlantic City was to report promptly to the test project contact with the light targets. At Newark the primary purpose of the commercial pilots was the operational landing of the aircraft. Their report was cooperative, but subsidiary to their normal routine.

The daytime curves are compared in Fig. 21. Again the range of ALCH values was slightly contracted for the Atlantic City tests. The slope of the curves showed a slight variation from those at Newark. This resulted in a trifling net difference of about 60 feet for the extreme case at the upper end of the range of cloud heights for which ALCH is derived. Although quite small, it was decided to determine the reason for the difference in slopes during the day, since the night slopes showed no marked difference.

TABLE IX

ALCH 90 PER CENT AND 20 PER CENT PROBABILITY VALUES VERSUS $\overline{H}_c$, LINEAR ANALYSIS - DAY

| $\overline{H}_c$ | $H_{.9}$ | $H_{.2}$ | $\overline{H}_c$ | $H_{.9}$ | $H_{.2}$ |
|---|---|---|---|---|---|
| 10 | 20 | 190 - | 410 | 200 | 370 |
| 20 | 30 | 200 - | 420 | 210 | 380 |
| 30 | 30 | 200 - | 430 | 210 | 380 |
| 40 | 30 | 210 - | 440 | 210 | 390 |
| 50 | 40 | 210 - | 450 | 220 | 390 |
| 60 | 40 | 210 - | 460 | 220 | 390 |
| 70 | 50 | 220 - | 470 | 230 | 400 |
| 80 | 50 | 220 - | 480 | 230 | 400 |
| 90 | 60 | 230 - | 490 | 240 | 410 |
| 100 | 60 | 230 - | 500 | 240 | 410 |
| 110 | 70 | 240 - | 510 | 250 | 420 |
| 120 | 70 | 240 - | 520 | 250 | 420 |
| 130 | 70 | 250 - | 530 | 260 | 430 |
| 140 | 80 | 250 - | 540 | 260 | 430 |
| 150 | 80 | 250 - | 550 | 260 | 440 |
| 160 | 90 | 260 - | 560 | 270 | 440 |
| 170 | 90 | 260 - | 570 | 270 | 440 |
| 180 | 100 | 270 - | 580 | 280 | 450 |
| 190 | 100 | 270 - | 590 | 280 | 450 |
| 200 | 110 | 280 | 600 | 290 | 460 |
| 210 | 110 | 280 | 610 | 290 | 460 |
| 220 | 120 | 290 | 620 | 300 | 470 |
| 230 | 120 | 290 | 630 | 300 | 470 |
| 240 | 120 | 300 | 640 | 310 | 480 |
| 250 | 130 | 300 | 650 | 310 | 480 |
| 260 | 130 | 300 | 660 | 310 | 490 |
| 270 | 140 | 310 | 670 | 320 | 490 |
| 280 | 140 | 310 | 680 | 320 | 490 |
| 290 | 150 | 320 | 690 | 330 | 500 |
| 300 | 150 | 320 | 700 | 330 | 500 |
| 310 | 160 | 330 | 710 | 340 | 510 |
| 320 | 160 | 330 | 720 | 340 | 510 |
| 330 | 170 | 340 | 730 | 350 | 520 |
| 340 | 170 | 340 | 740 | 350 | 520 |
| 350 | 170 | 350 | 750 | 360 | 530 |
| 360 | 180 | 350 | 760 | 360 | 530 |
| 370 | 180 | 350 | 770 | 360 | 540 |
| 380 | 190 | 360 | 780 | 370 | 540 |
| 390 | 190 | 360 | 790 | 370 | 540 |
| 400 | 200 | 370 | 800 | 380 | 550 |

(-) Indicates that only $H_{.2}$ values should be disseminated for operational use at these values of $H_c$.

## TABLE X

### ALCH 90 PER CENT AND 20 PER CENT PROBABILITY VALUES VERSUS $\overline{H}_c$ LINEAR ANALYSIS - NIGHT

| $\overline{H}_c$ | $H_{.9}$ | $H_{.2}$ | $\overline{H}_c$ | $H_{.9}$ | $H_{.2}$ |
|---|---|---|---|---|---|
| 10 | 40 | 200 - | 410 | 270 | 430 |
| 20 | 40 | 200 - | 420 | 270 | 440 |
| 30 | 50 | 210 - | 430 | 280 | 440 |
| 40 | 50 | 220 - | 440 | 280 | 450 |
| 50 | 60 | 220 - | 450 | 290 | 450 |
| 60 | 60 | 230 - | 460 | 300 | 460 |
| 70 | 70 | 230 - | 470 | 300 | 460 |
| 80 | 80 | 240 - | 480 | 310 | 470 |
| 90 | 80 | 240 - | 490 | 310 | 480 |
| 100 | 90 | 250 - | 500 | 320 | 480 |
| 110 | 90 | 260 - | 510 | 330 | 490 |
| 120 | 100 | 260 - | 520 | 330 | 490 |
| 130 | 110 | 270 | 530 | 340 | 500 |
| 140 | 110 | 270 | 540 | 340 | 500 |
| 150 | 120 | 280 | 550 | 350 | 510 |
| 160 | 120 | 280 | 560 | 350 | 520 |
| 170 | 130 | 290 | 570 | 360 | 520 |
| 180 | 130 | 300 | 580 | 370 | 530 |
| 190 | 140 | 300 | 590 | 370 | 530 |
| 200 | 150 | 310 | 600 | 380 | 540 |
| 210 | 150 | 310 | 610 | 380 | 550 |
| 220 | 160 | 320 | 620 | 390 | 550 |
| 230 | 160 | 330 | 630 | 390 | 560 |
| 240 | 170 | 330 | 640 | 400 | 560 |
| 250 | 170 | 340 | 650 | 410 | 570 |
| 260 | 180 | 340 | 660 | 410 | 570 |
| 270 | 190 | 350 | 670 | 420 | 580 |
| 280 | 190 | 350 | 680 | 420 | 590 |
| 290 | 200 | 360 | 690 | 430 | 590 |
| 300 | 200 | 370 | 700 | 440 | 600 |
| 310 | 210 | 270 | 710 | 440 | 600 |
| 320 | 220 | 380 | 720 | 450 | 610 |
| 330 | 220 | 380 | 730 | 450 | 610 |
| 340 | 230 | 390 | 740 | 460 | 620 |
| 350 | 230 | 390 | 750 | 460 | 630 |
| 360 | 240 | 400 | 760 | 470 | 630 |
| 370 | 240 | 410 | 770 | 480 | 640 |
| 380 | 250 | 410 | 780 | 480 | 640 |
| 390 | 260 | 420 | 790 | 490 | 650 |
| 400 | 260 | 420 | 800 | 490 | 660 |

(-) Indicates that only $H_{.2}$ values should be disseminated for operational use at these values of $\overline{H}_c$.

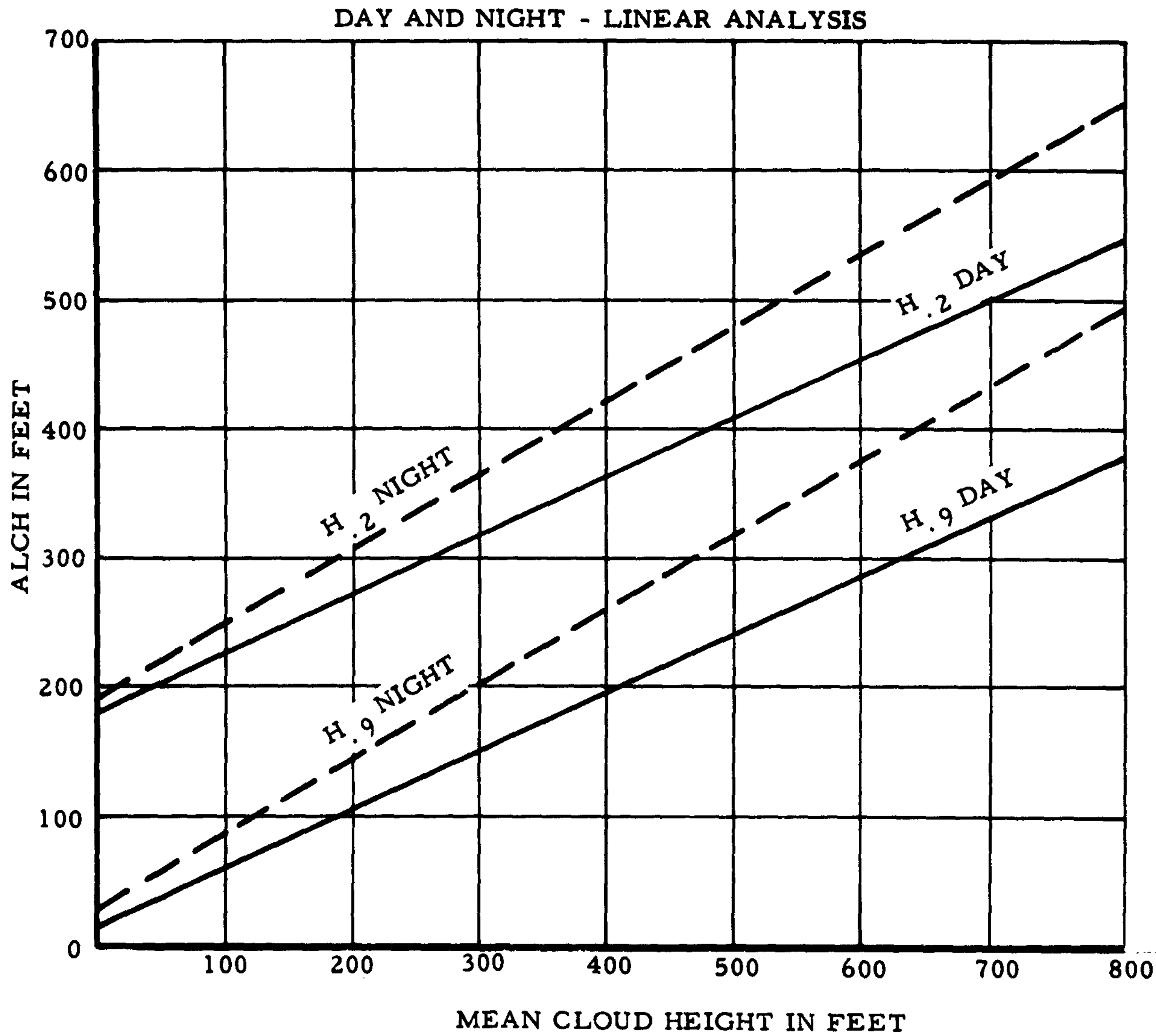



FIG. 18 COMPARISON OF ATLANTIC CITY ALCH CURVES VS. MEAN CLOUD HEIGHT

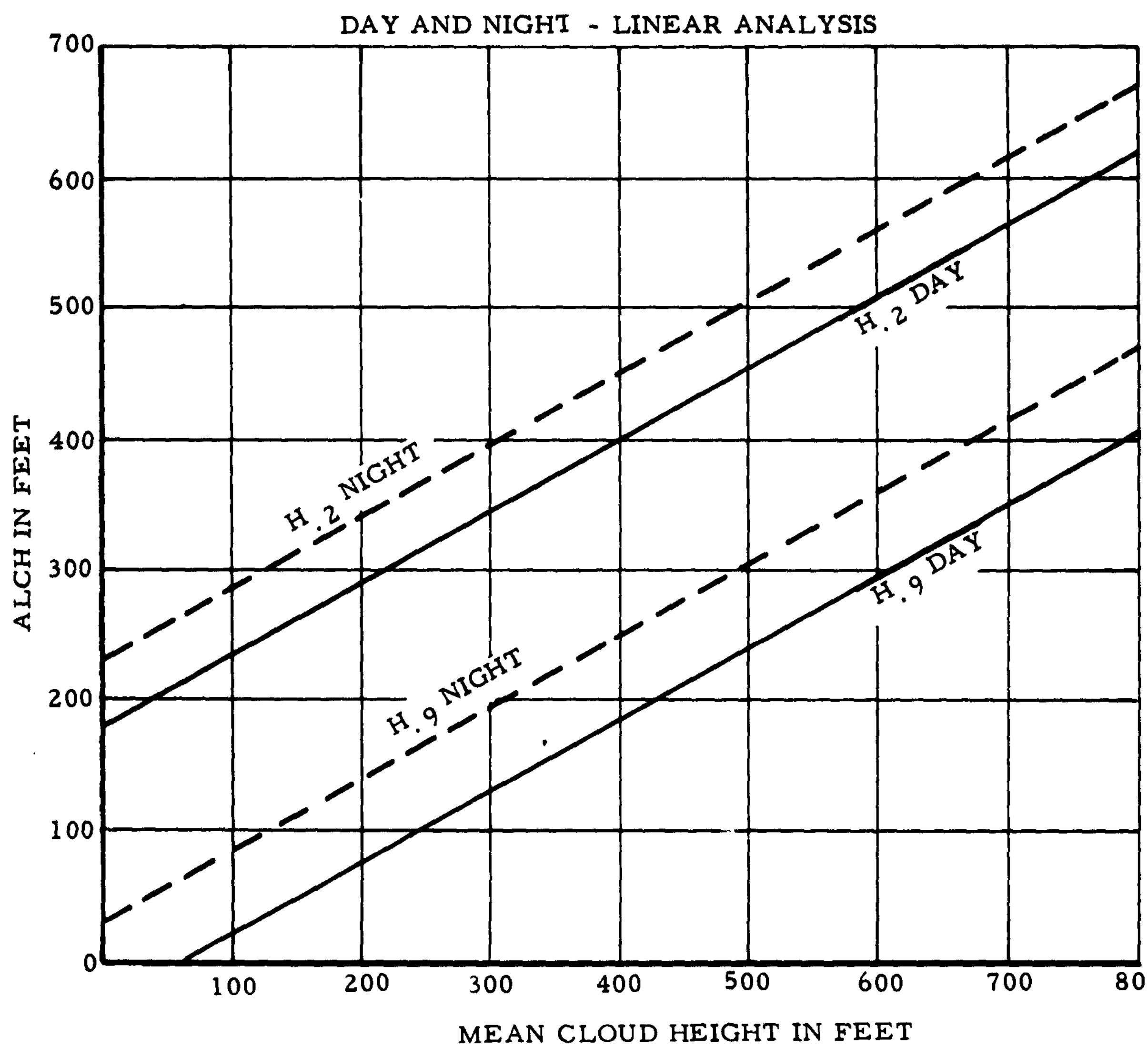



FIG. 19 COMPARISON OF NEWARK ALCH CURVES VS. MEAN CLOUD HEIGHT

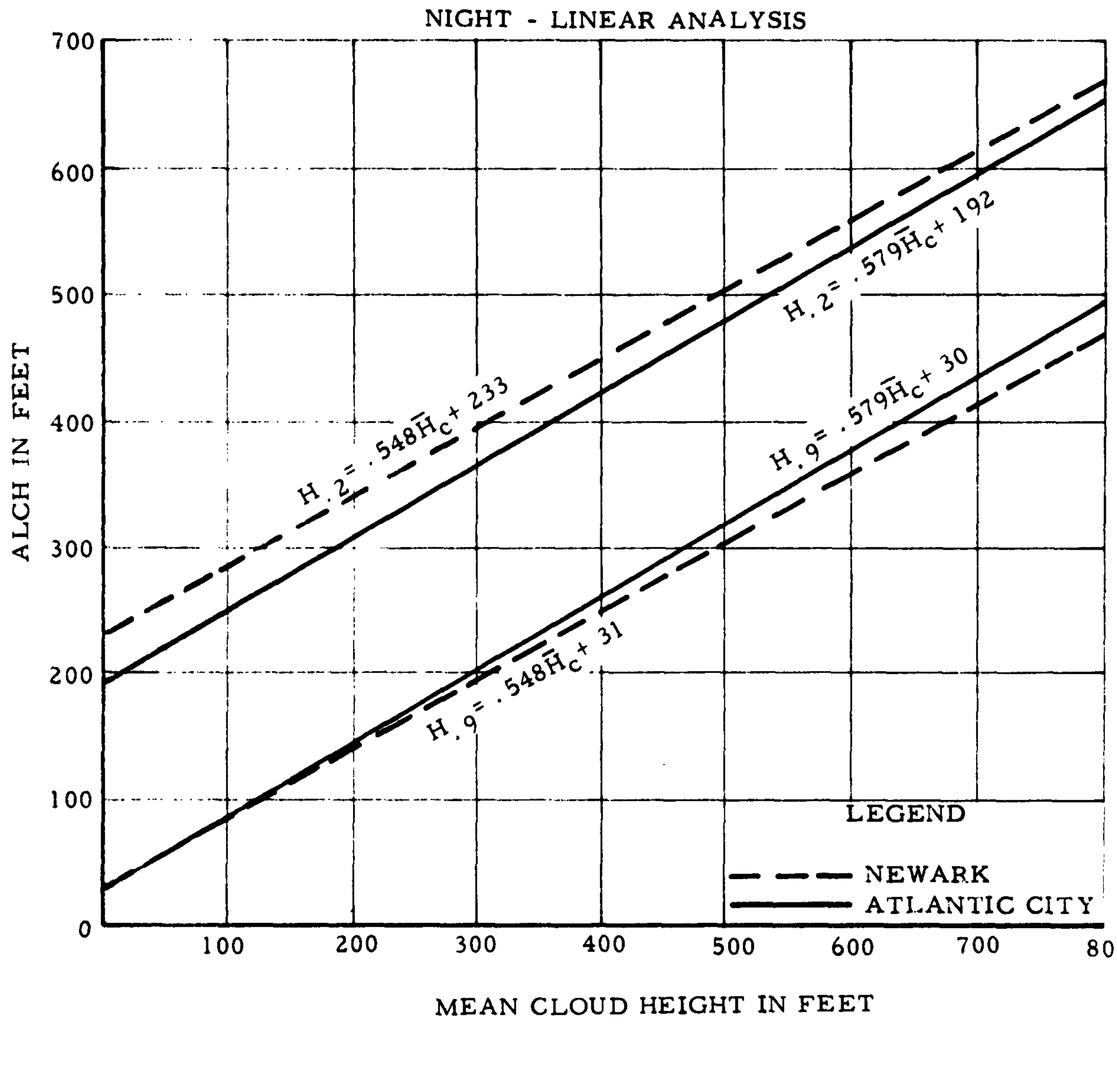



**FIG. 20 COMPARISON OF NEWARK AND ATLANTIC CITY ALCH CURVES VS. MEAN CLOUD HEIGHT**

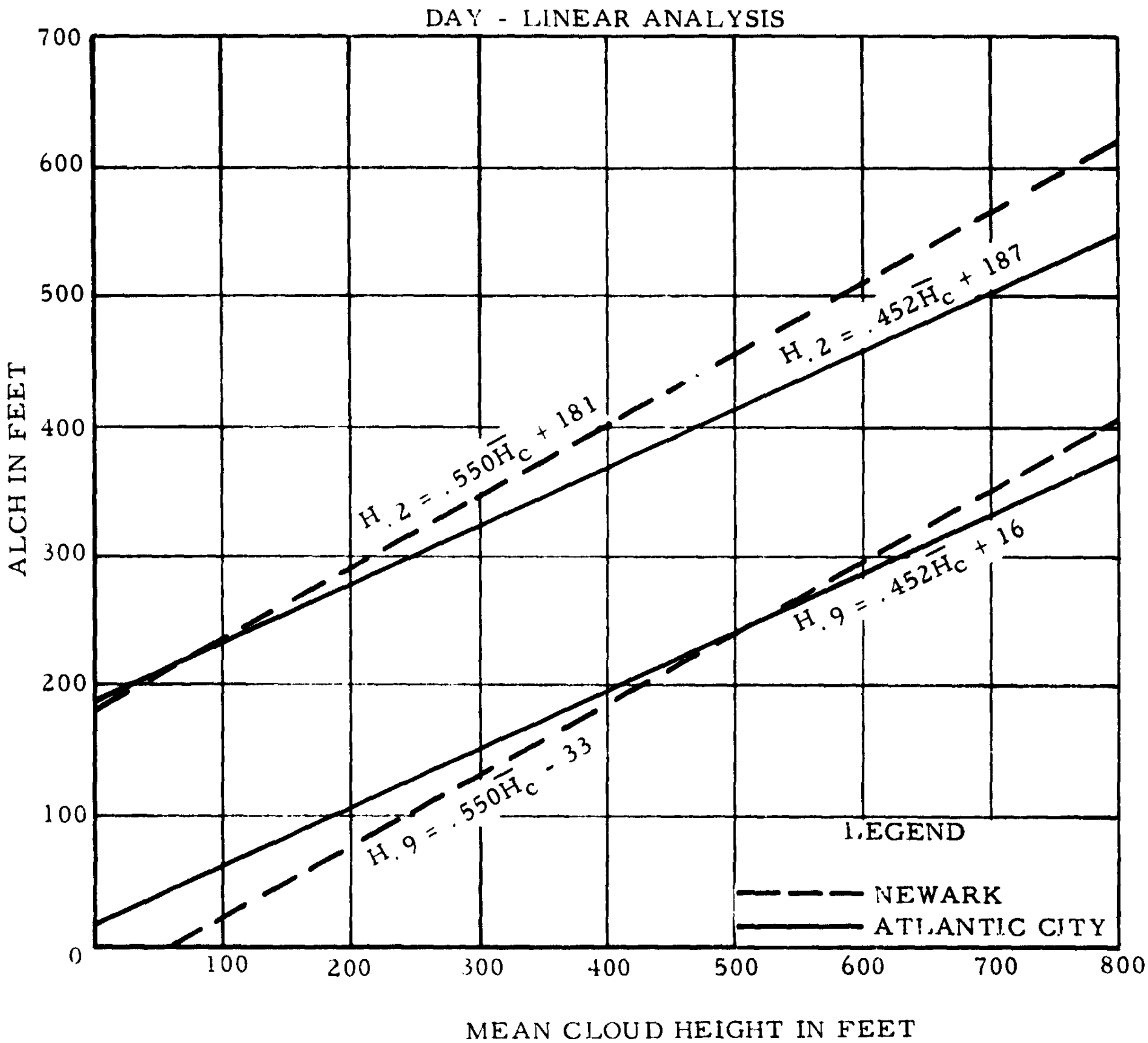



FIG. 21 COMPARISON OF NEWARK AND ATLANTIC CITY ALCH CURVES VS. MEAN CLOUD HEIGHT

Discussions with pilots revealed that there is little to serve as visual cues on the approach to the instrument runway at Atlantic City in the presence of low clouds. When vertical, or over-the-nose contact is established, pilot search time is required to establish slant contact with the approach light array. This was not the case at Newark. The New Jersey Turnpike served as an outstanding visual cue during the day, Fig. 22, guiding the pilot directly to the approach light array and effectively decreasing pilot search time. At night the highway had insufficient illumination to serve as a guide. This geographical contribution decreased the required search time at Newark, and permitted the pilots to contact the approach lights at a somewhat higher altitude than at Atlantic City under the same cloud height conditions. As cloud heights became lower, the decrease in search time was proportionally reduced. This caused the effect to be greatest at the higher cloud heights, and relatively insignificant at the lower cloud heights.

The Atlantic City curves are considered representative of a controlled test program. The Newark curves are applicable to operational pilots with experience in making ILS approaches to a specific airport during weather conditions of low ceiling and visibility.

## Evaluation of ALCH, HF Category

### 1. Background

Under conditions when atmospheric transmission, rather than low clouds, is the dominant limitation to the pilot's slant visual range, ALCH is based on the concept of Allard's Law (References 5 and 8). Insufficient data were acquired at Atlantic City to permit a thoroughly comprehensive evaluation of the HF values and empirical constants developed at Newark. This part, nevertheless, examines all available data, to the most valid extent, and applies the results as a basic evaluation indicant of Newark.

### 2. Data Analysis

Allard's Law is generally expressed:

$$E_t = \frac{I\,(T_B)^{V/B}}{V^2} \tag{12}$$

where $E_t$ = pilot's visual illuminance threshold,

I = light target intensity,


FIG. 22 GEOGRAPHICAL RELATIONSHIP - RUNWAY 4-22 NEWARK AIRPORT AND NEW JERSEY TURNPIKE

$T_B$ = integral mean atmospheric transmission (over path length B) along the actual line of sight,

V = pilot's visual range to the light target,

B = the transmission path length.

For purposes of direct comparison with Newark data, the values for the empirical constant $E_t$ were first derived from the Atlantic City test flights utilizing techniques and assumptions compatible with the Newark methods. While discussed in considerable detail in Reference 1, the basic assumptions are, briefly:

a. The light target was a composite system consisting of EFAS and steady burning bar lights. The value of I (Table I) was determined by the maximum intensity ascribed to the steady-burning bar lights for the step setting in effect at the time of the pilot's report of approach light contact.

b. $T_B$ was represented as that sampling of transmission obtained from the touchdown transmissometer along baseline length B, at the time of the pilot's report of contact.

c. The pilot's slant visual range V was computed geometrically from the measured values of aircraft height at the time of the pilot's report($H_{AR}$)and the range from end of runway (RER). This information was obtained from photographs of the elevation display of the GCA MPN-11 radar.

d. The cockpit cutoff angle of the aircraft was assumed to be 15°.

e. A minimum guidance distance of 500 feet would be required by the pilot before he could adequately utilize the approach lights.

The variables in equation (12) were derived in accordance with the Newark assumptions and a cumulative percentage frequency distribution developed for $E_t$, based on the Atlantic City data. Listed in Table XI under "composite" approach light intensity are the Atlantic City and Newark 20 per cent and 90 per cent probability $E_t$ values ($E_{t.2}$, $E_{t.9}$) for purposes of comparison. The range of data, as well as the order of magnitude, is evidence of a strong relationship between the empirical constant $E_t$ obtained at Newark and the comparable Atlantic City constant.

## TABLE XI

### COMPARISON OF 20 PER CENT AND 90 PER CENT PROBABILITY VALUES OF $E_t$ AND C FOR HF DATA AT ATLANTIC CITY AND NEWARK

| Location | Day or Night | No. of Cases | Light Intensity | Log $E_{t\,.9}$ | $E_{t\,.9}$ (lumens/ft.$^2$) | Log $E_{t\,.2}$ | $E_{t\,.2}$ (lumens/ft.$^2$) | $C_{.9}$ | $C_{.2}$ |
|---|---|---|---|---|---|---|---|---|---|
| Atlantic City | Night | 39 | Composite | -4. 11000 | $.7763 \times 10^{-4}$ | -5. 50000 | $3.162 \times 10^{-6}$ | -4. 05000 | -4. 67000 |
| Newark | Night | 61 | Composite | -3. 85387 | $1.4 \times 10^{-4}$ | -6. 72125 | $.19 \times 10^{-6}$ | -3. 62950 | -4. 88850 |
| Atlantic City | Night | 39 | 15, 000 cp. | -3. 92391 | $1.191 \times 10^{-4}$ | -5. 16391 | $6.856 \times 10^{-6}$ | -4. 05000 | -4. 67000 |
| Newark | Night | 61 | 15, 000 cp. | -3. 08291 | $8.262 \times 10^{-4}$ | -5. 60091 | $2.507 \times 10^{-6}$ | -3. 62950 | -4. 88850 |
| Atlantic City | Day | 9 | Composite | -2. 18000 | $6.607 \times 10^{-3}$ | -3. 69000 | $2.042 \times 10^{-4}$ | -3. 44000 | -3. 97000 |
| Newark | Day | 314 | Composite | -2. 82391 | $1.5 \times 10^{-3}$ | -4. 85387 | $.14 \times 10^{-4}$ | -3. 46060 | -4. 42670 |
| Atlantic City | Day | 9 | 15, 000 cp. | -2. 70391 | $1.977 \times 10^{-3}$ | -3. 76391 | $1.722 \times 10^{-4}$ | -3. 44000 | -3. 97000 |
| Newark | Day | 314 | 15. 000 cp. | -2. 74511 | $1.798 \times 10^{-3}$ | -4. 67731 | $.2102 \times 10^{-4}$ | -3. 46060 | -4. 42670 |

As a result of the controlled flight test program at Atlantic City, all pilot reports of light target contacts were clearly identified with respect to the targets sighted. This control could not be fully exercised over the operational pilots on whom the Newark data were based. To eliminate any element of uncertainty that might result from target identification, as well as to avoid the complex photometric problem of the EFAS embedded in a steady burning, variable intensity, approach light array (Newark assumption a., page 52) an alternate method was developed for determining empirical constants.

Allard's Law may also be expressed:

$$\frac{E_t}{I} = \frac{(T_B)^{V/B}}{V^2} \tag{13}$$

and:

$$\sqrt{\frac{E_t}{I}} = \frac{(T_B)^{V/2B}}{V} \tag{14}$$

Therefore, C, a physical constant, may be defined:

$$C = \log\sqrt{\frac{E_t}{I}} = \log\left[\frac{(T_B)^{V/2B}}{V}\right] \tag{15}$$

In the flight test programs, the position of an aircraft was fixed in space by photographing the radar display at the instant the pilot reported sighting a light target. For each sighting there is a specific $T_B$ which is assumed representative of the pilot's environment, and a value of V determined from the pertinent $H_{AR}$. Consequently, the values of V and $T_B$ are fixed for that approach. Hence, C is equally fixed and determined without using a value of I. A cumulative percentage frequency curve of C may now be derived, based on the more certain Newark assumptions b. through e., and eliminating the relative uncertainties of assumption a.

The cumulative percentage frequency distributions of C determined at Atlantic City are compared in Fig. 23 with like data obtained at Newark. While the Atlantic City data sample is restricted and lacks sufficient normality of distribution to fully validate this statistical approach, the range of data and similarity of curves are considered indicative of a good correlation between the Atlantic City and Newark empirical constants. The 20 per cent and 90 per cent values for C at the two test stations are compared in Table XI.

An I value of 15,000 candlepower (effective intensity of EFAS or steady-burning approach lights at maximum) has been introduced in equation (15) as the logical target in the approach light array, and $E_{t_p}$ derived. These are listed in Table XI for the clearly identified light target sightings at Atlantic City, as compared to the like Newark data.

The similarity of the constant C, determined at Atlantic City and Newark, is presented in Figs. 24 and 25. Values of $T_{500}$ for I = 15,000 candlepower have been plotted against V for various $C_p$ constants for night and day. The $C_p$ curves derived at Newark encompass the Atlantic City $C_p$ values. This is analogous to results obtained in the analysis of the ALCH low-cloud category.

The limited Atlantic City data prevent extending the foregoing analyses to an appraisal of discrete ALCH values for HF. However, in order to obtain a qualitative insight, an HF data score was prepared for Atlantic City based on the Newark ALCH empirically derived tables (Table XII). The score indicates that for both day and night test approaches, 100 per cent of the ALCH reports took place when the aircraft was at a height between the 20 per cent and 90 per cent probability levels. Ideally, 70 per cent of the reports should have been made between those levels. Were a greater data sample available and the Newark ALCH tables thus further refined, a more idealized report distribution might have been realized. Nevertheless, while the ALCH concept under restricted visibility conditions could not be fully verified at Atlantic City due to the lack of sufficient data, there was no evidence that the Newark results were other than reasonably accurate and conservative.

3. Slant Range - Height Relationship

For any given value of V, aircraft height is sensitive to position relative to the glide slope. A study was made of the relationship between $H_{AR}$ and RER. The 50 HF and snow approaches were utilized and the line of best fit glide slope determined to be:

$$H_{AR} = 0.047 \text{ RER} + 62 \qquad (16)$$

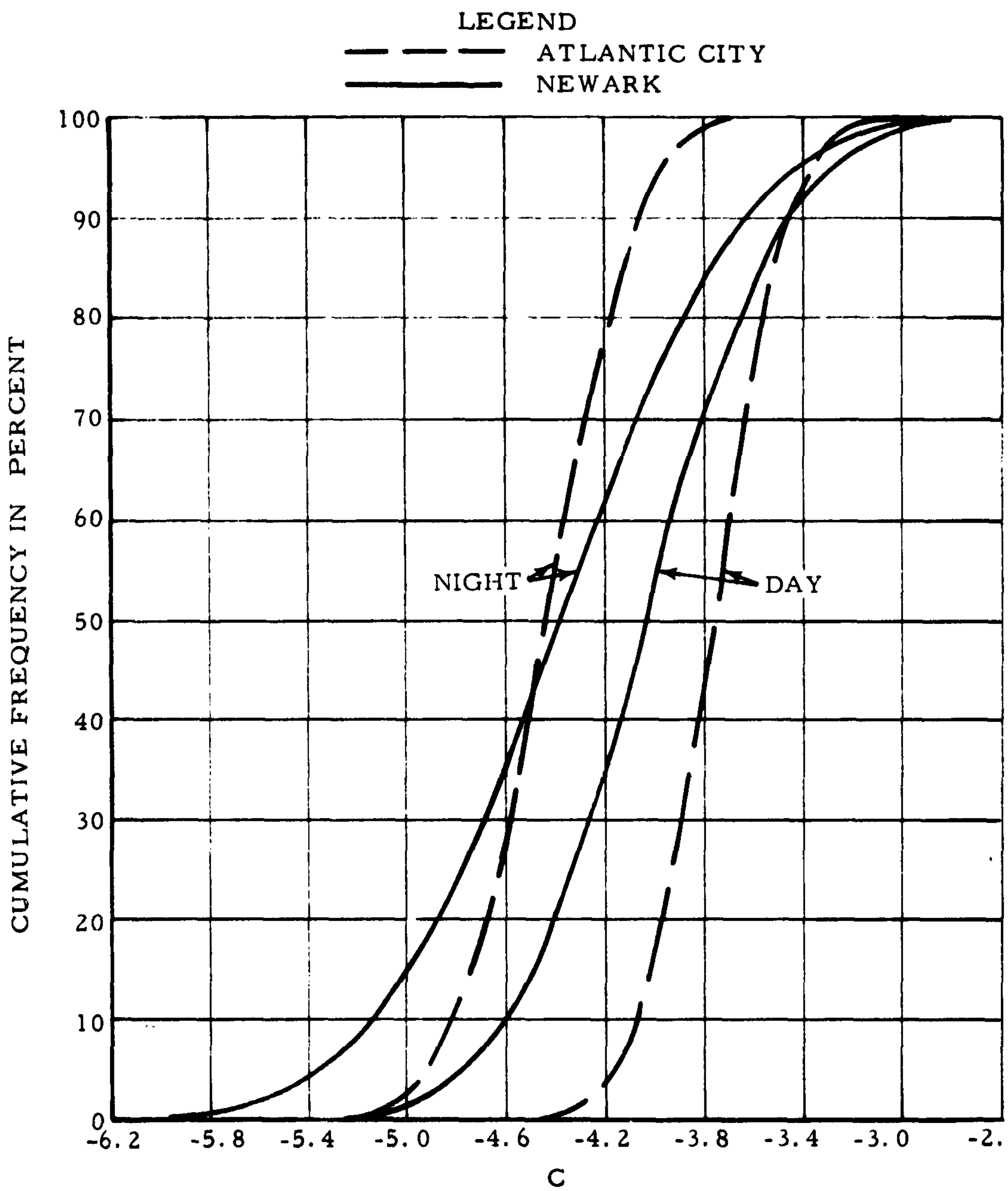



FIG. 23 CUMULATIVE FREQUENCY DISTRIBUTION OF C FOR HF CONDITIONS

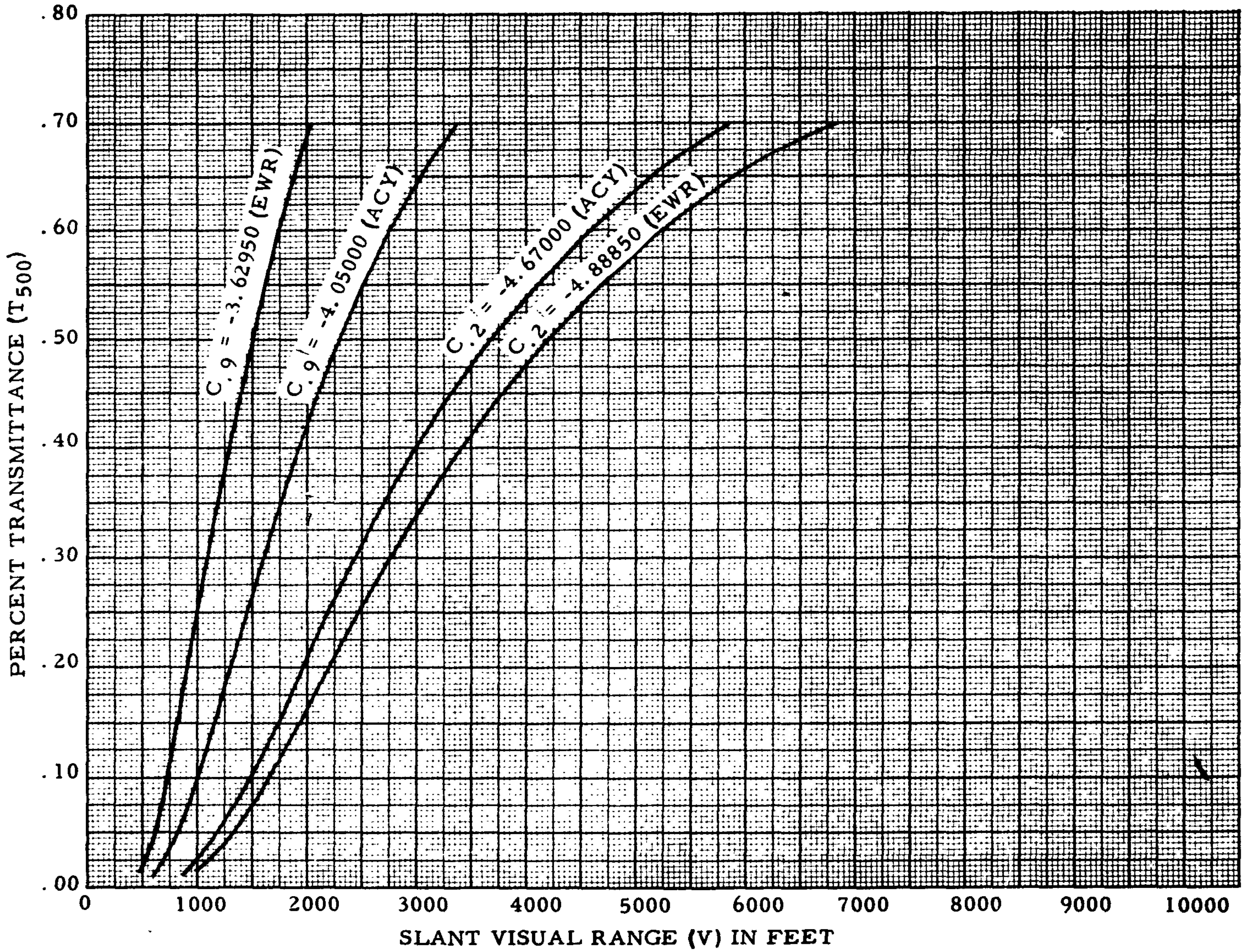



FIG. 24 VARIATION OF $T_{500}$ WITH V FOR SPECIFIED ATLANTIC CITY

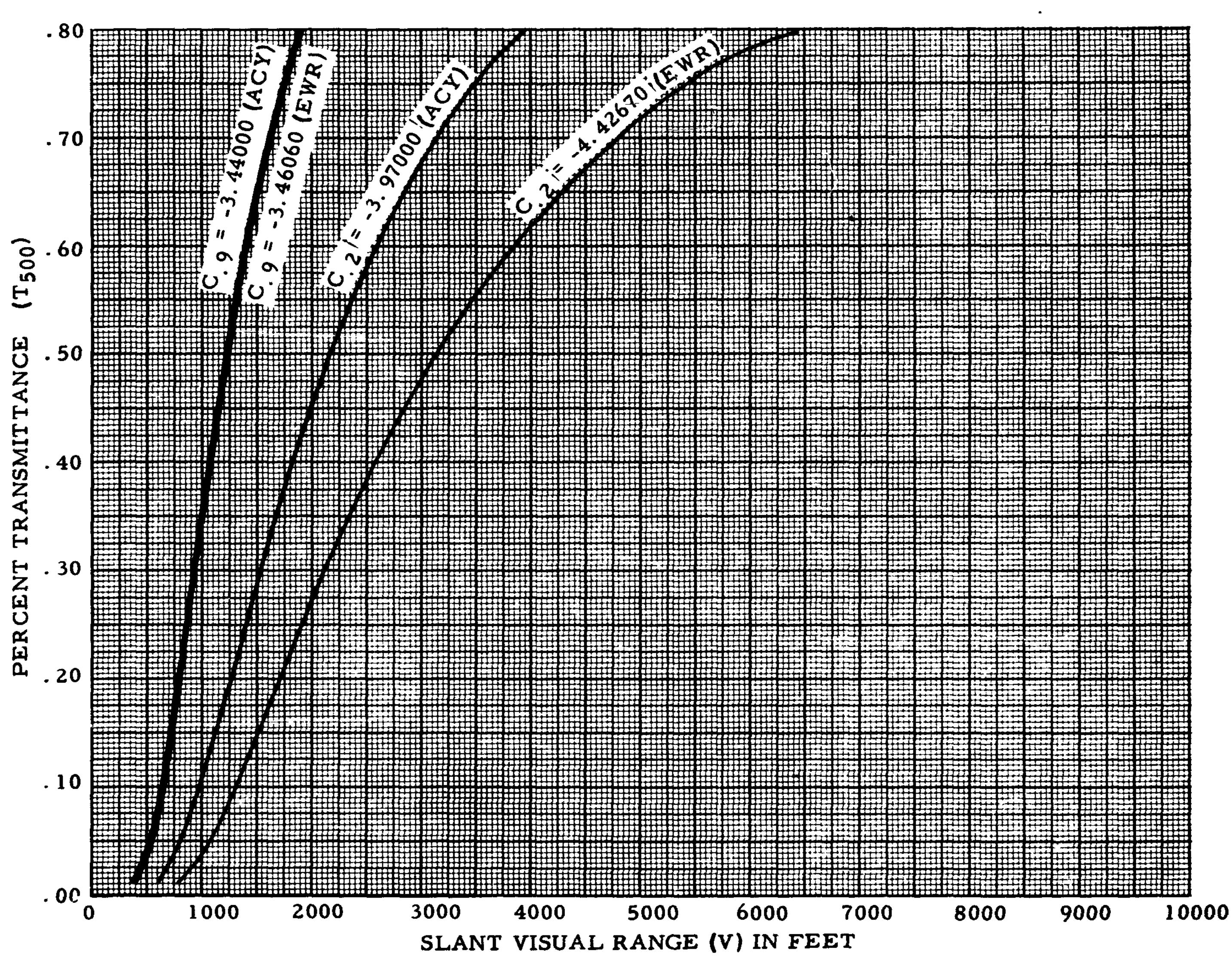



FIG. 25 VARIATION OF $T_{500}$ WITH V FOR SPECIFIED ATLANTIC CITY AND NEWARK VALUES OF $C_p$, I = 15,000 CP, DAY

TABLE XII

ATLANTIC CITY

FINAL DATA SCORE

(Based on Newark ALCH curves)

| | HF | P |
|---|---|---|
| Valid ALCH reports, day and night | n = 0<br>0% | |
| | | .2 |
| | n = 48<br>100% | |
| | | .9 |
| | n = 0<br>0% | |
| Valid ALCH reports, day | n = 0<br>0% | |
| | | .2 |
| | n = 9<br>100% | |
| | | .9 |
| | n = 0<br>0% | |
| Valid ALCH reports, night | n = 0<br>0% | |
| | | .2 |
| | n = 39<br>100% | |
| | | .9 |
| | n = 0<br>0% | |

The geometry of the line of best fit glide slope at Atlantic City can be seen in Fig. 26. Significantly, the studies at Atlantic City and Newark confirm the observation that under IFR weather conditions pilots generally tend to fly above the glide slope until visual contact is made with the approach lighting system. While the published glide slope represents idealized instrumental guidance, the line of best fit glide slope (derived from the actual paths of flight) at Atlantic City makes an angle of 2.69° with the plane of the runway near touchdown, compared to the official glide slope angle of 2.59°. The linear correlation coefficient is 0.840. The comparable values for Newark are: line of best fit glide slope angle, 3.08°; official glide slope angle, 2.8°; linear correlation coefficient, 0.856.

To operationally apply the empirically derived values of HF ALCH to the greatest advantage of the IFR pilot, the line of best fit glide slope is preferred. The HF ALCH tables can thus be developed on a more reasonably assumed path of flight, and would be responsive to a glide slope angle greater than the published figure, and the confirmation provided by the significant correlation coefficient. While insufficient data were available to prepare HF ALCH tables at Atlantic City, it is interesting to note that the glide slope angle departures and the magnitudes of the correlation coefficients were similar at Newark and Atlantic City.

## Operational Application of ALCH

The comparisons in Figs. 27 and 28 of the current ALCH method with average approach-zone cloud height and the conventional method of reporting cloud height in aviation weather reports illustrate the effectiveness of a rapidly measured and reported index of a pilot's recognition of such ground features as approach lighting. In this case the index considers cloud height in an empirical relationship with another important meteorological parameter, the opacity of the atmosphere. The comparisons indicate that the value of ALCH as a method of terminal weather reporting is most apparent at the lower and higher cloud heights. The data further reveal the closer relationship established by the pilot's $H_{AR}$ with ALCH than with the conventional method of reporting ceiling, or with $\overline{H}_c$ (average approach-zone cloud height). It should be pointed out that in comparison between ALCH and the conventional cloud height measuring techniques the latter are at a disadvantage partially because of the time lag which exists due to slow communication of the ceiling height to the pilot under presently

D = MINIMUM GUIDANCE SEGMENT (500')
V = SLANT VISUAL RANGE
h = APPROACH LIGHT CONTACT HEIGHT
$\alpha$ = LINE OF BEST FIT GLIDE SLOPE ANGLE
$\beta$ = COCKPIT CUTOFF ANGLE (15°)
A = 1319' + 3010' = 4329'
A - D = 3829'
$(A-D)^2$ = 14,661,241'

$\alpha = 2.69°$
$\text{ctn}\ \alpha = 21.278$
$\text{ctn}^2\ \alpha = 452.753$
$\text{ctn}^2\alpha + 1 = 453.753$

$\beta = 15°$
$\text{ctn}\ \beta = 3.7321$
$\tan \beta = .26795$

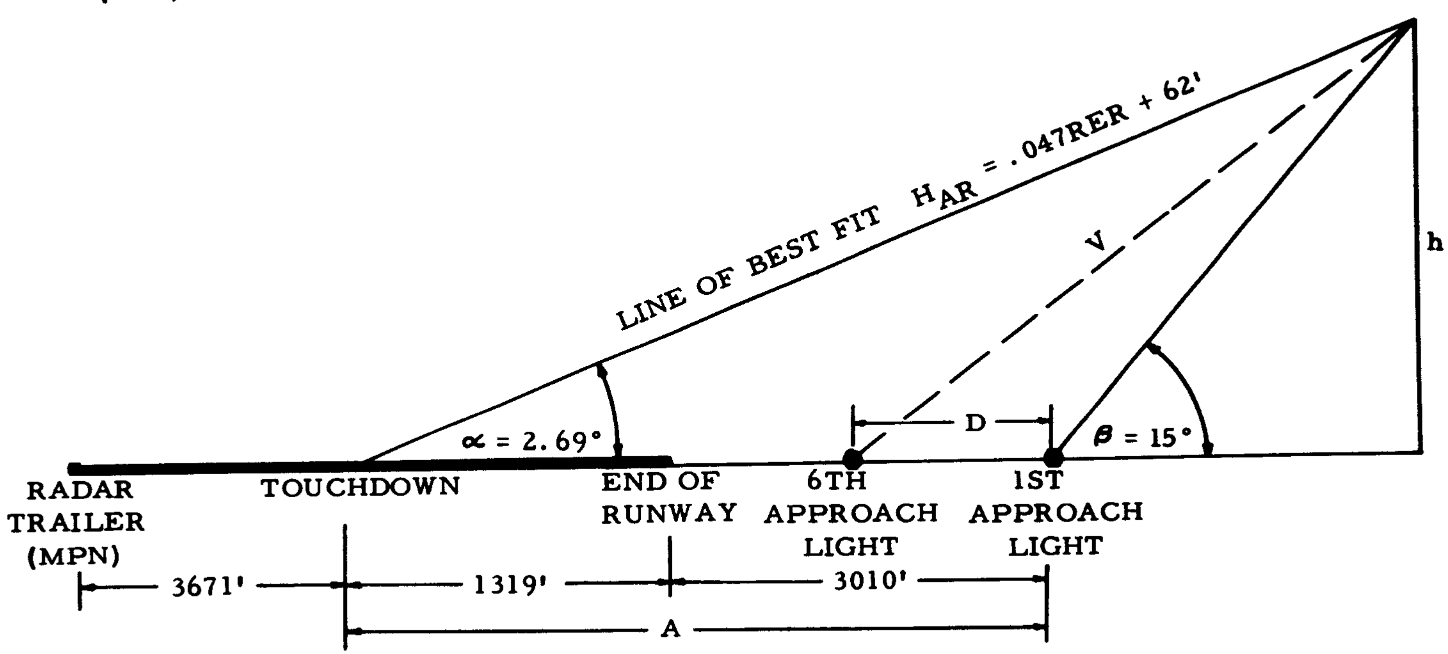



FIG. 26 GEOMETRY OF APPROACH BASED ON LINE OF BEST FIT ATLANTIC CITY, N. J.

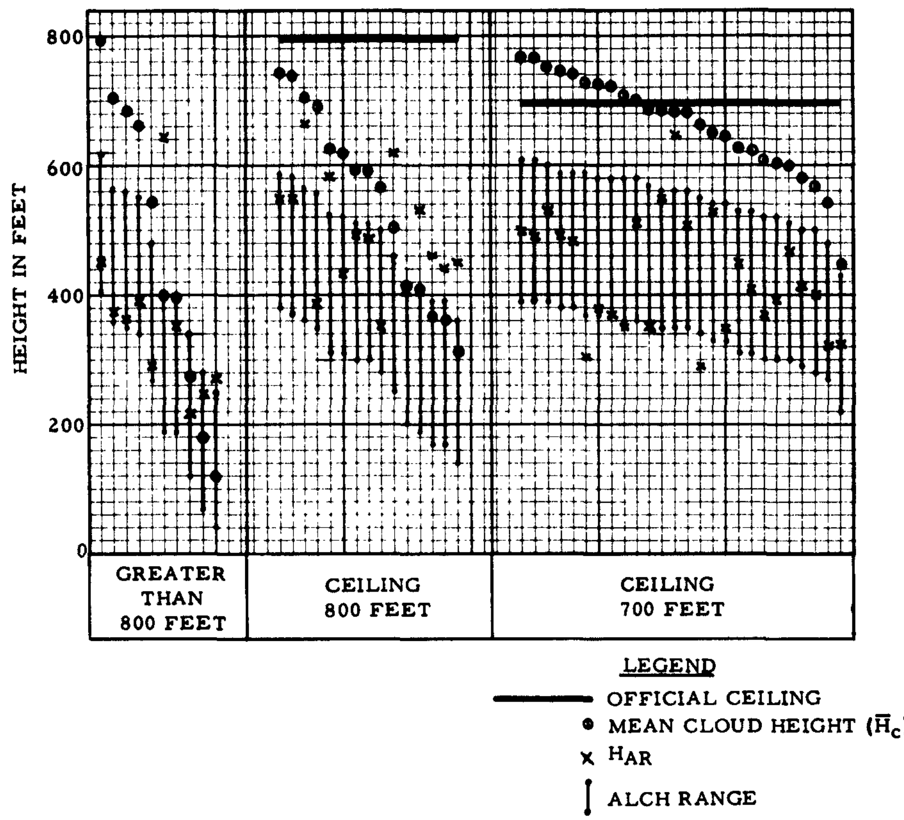



FIG. 27a OFFICIAL CEILINGS SHOWING $\bar{H}_c$, $H_{AR}$, AND ALCH RELATIONSHIPS - DAY - (CEILING GREATER THAN 800 FEET, 800 FEET, AND 700 FEET)

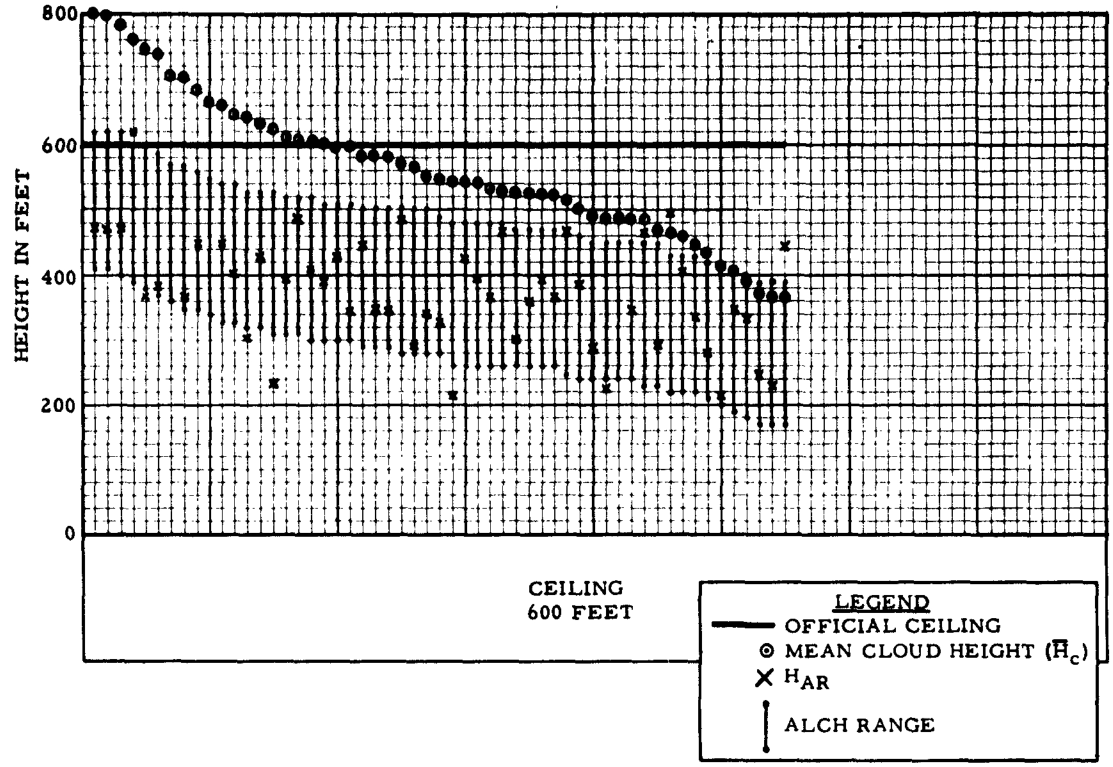



FIG. 27b OFFICIAL CEILINGS SHOWING $\overline{H}_c$, $H_{AR}$, AND ALCH RELATIONSHIPS - DAY - (CEILING OF 600 FEET)

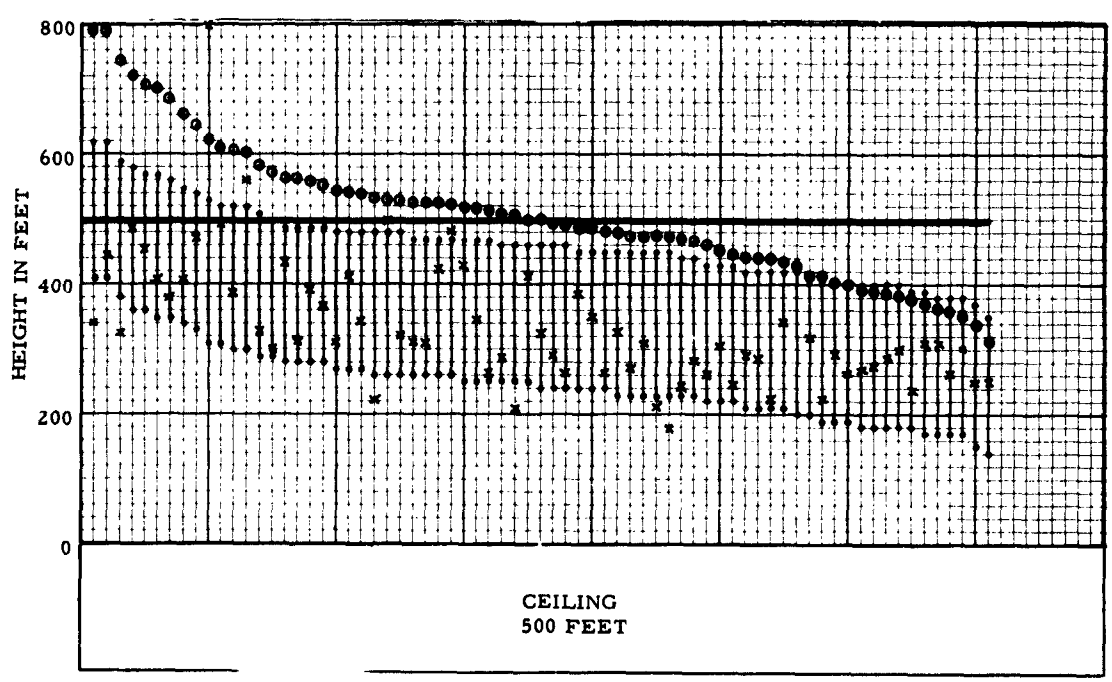



FIG. 27c OFFICIAL CEILINGS SHOWING $\overline{H}_c$, $H_{AR}$, AND ALCH RELATIONSHIPS - DAY - CEILING OF 500 FEET)

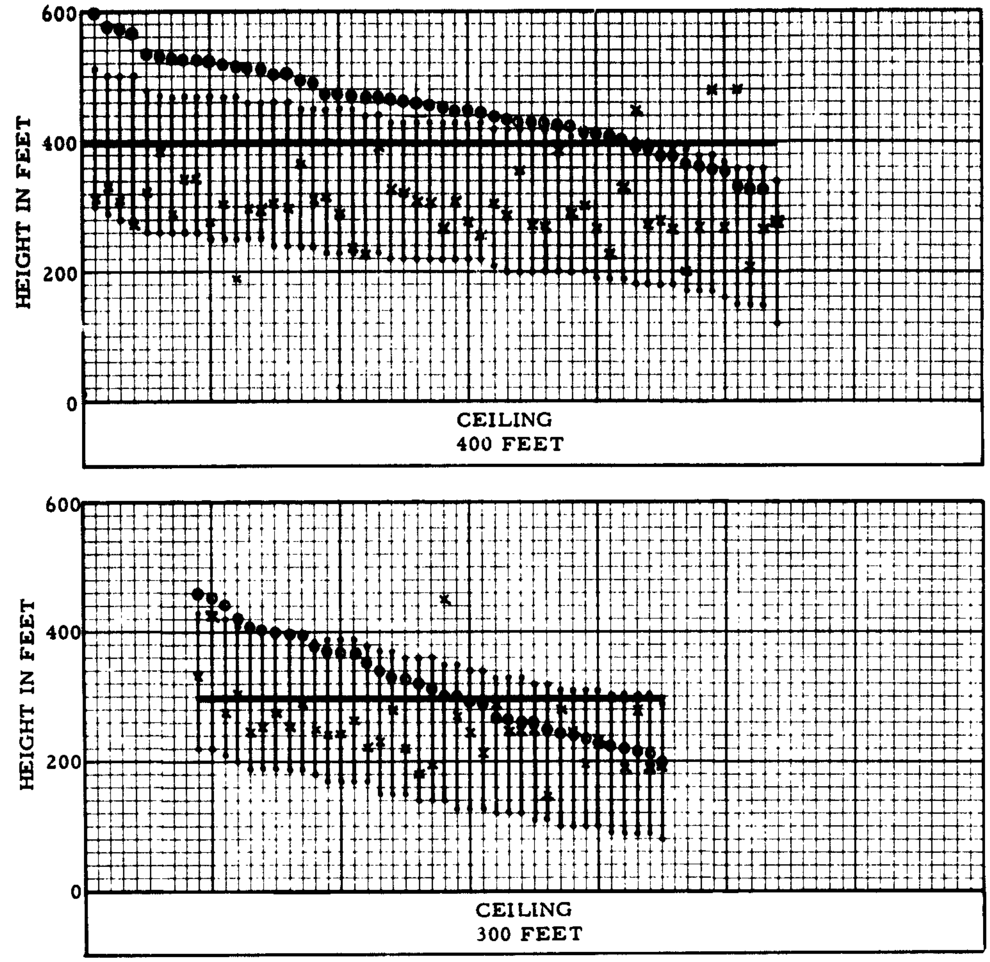



FIG. 27d OFFICIAL CEILINGS SHOWING $\overline{H}_c$, $H_{AR}$, AND ALCH RELATIONSHIPS - DAY - (CEILINGS OF 400 FEET AND 300 FEET)

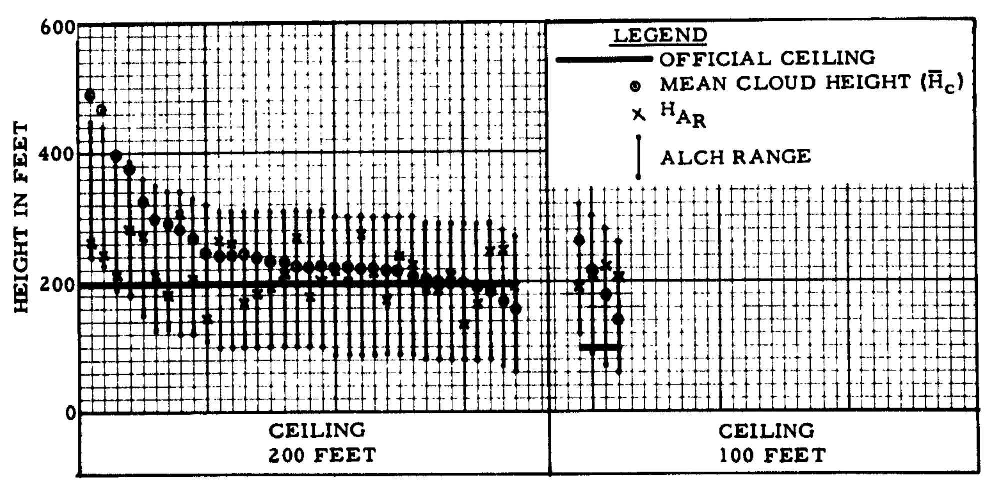



FIG. 27e OFFICIAL CEILINGS SHOWING $\overline{H}_c$, $H_{AR}$, AND ALCH RELATIONSHIPS - DAY - (CEILINGS OF 200 FEET AND 100 FEET)

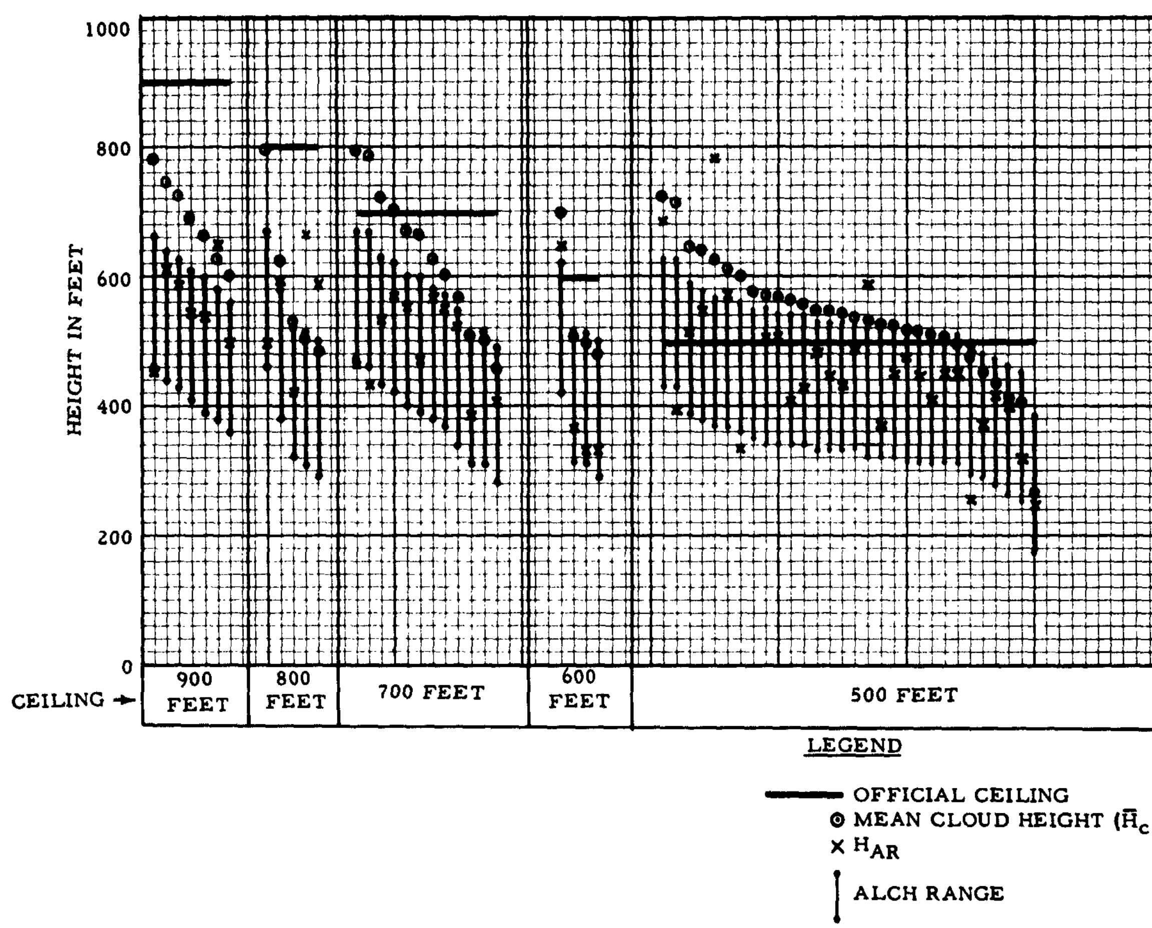



FIG. 28a OFFICIAL CEILINGS SHOWING $\overline{H}_c$, $H_{AR}$, AND ALCH RELATIONSHIPS - NIGHT - (CEILINGS OF 900 FEET, 800 FEET, 700 FEET, 600 FEET, AND 500 FEET)

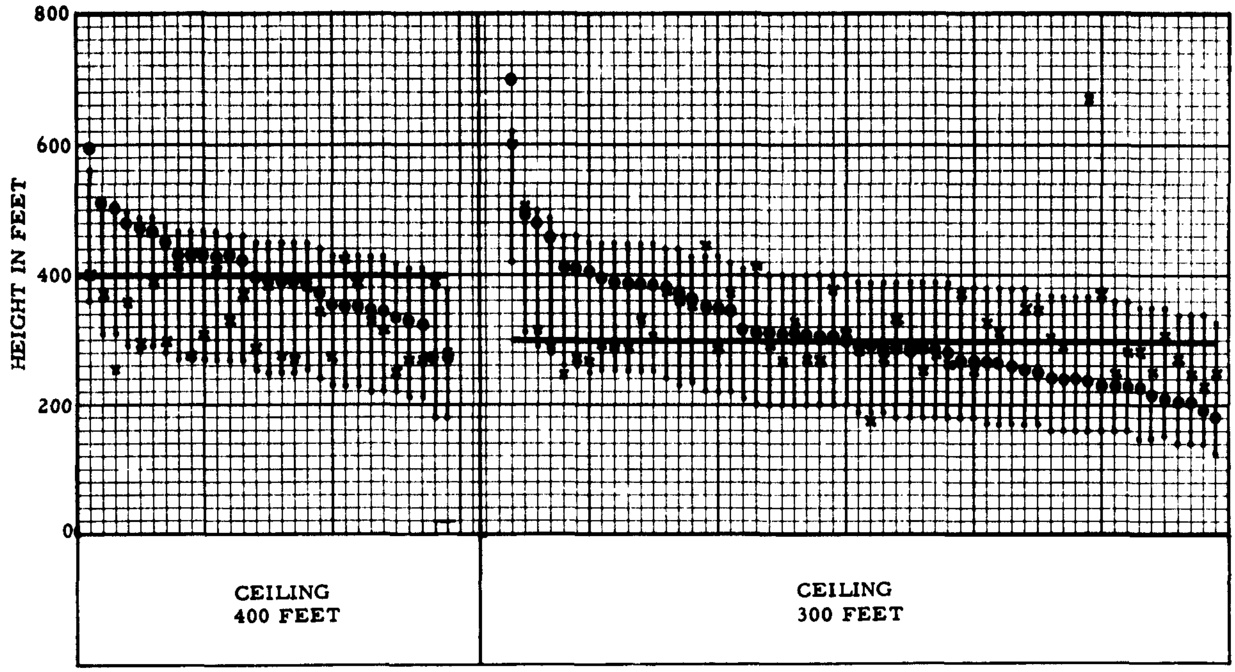



FIG. 28b OFFICIAL CEILINGS SHOWING $\overline{H}_c$, $H_{AR}$, AND ALCH RELATIONSHIPS - NIGHT - (CEILINGS OF 400 FEET AND 300 FEET)

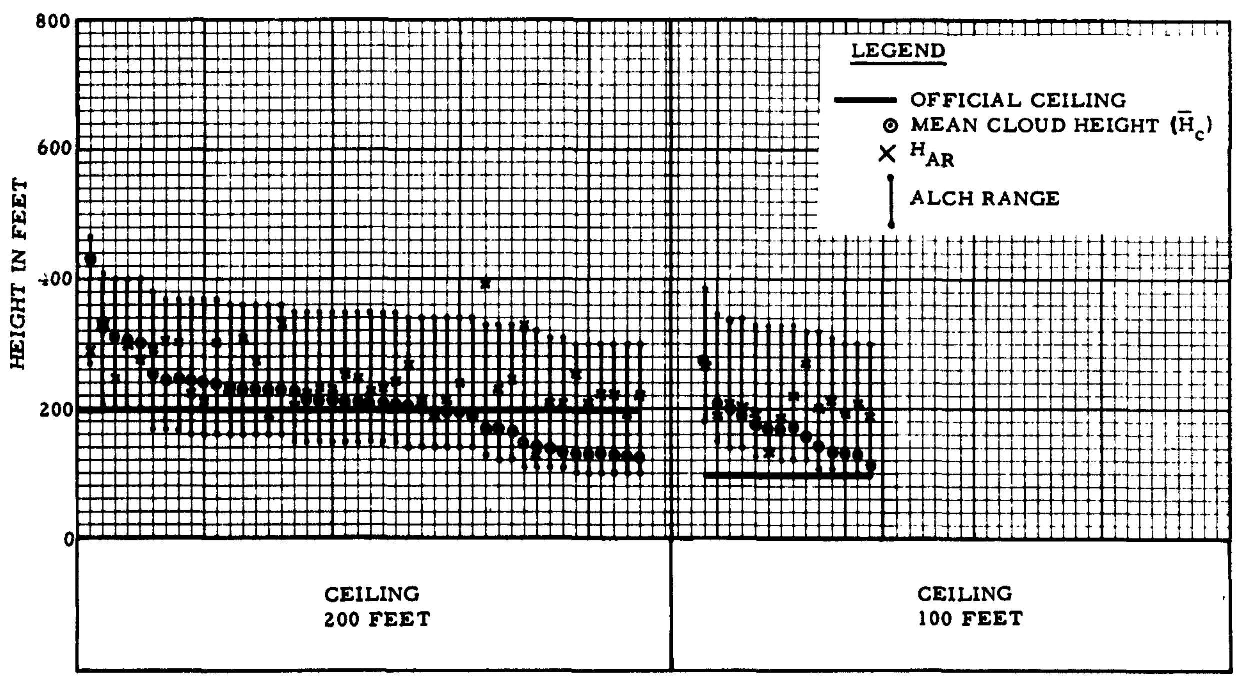



FIG. 28c OFFICIAL CEILINGS SHOWING $\overline{H}_c$, $H_{AR}$, AND ALCH RELATIONSHIPS - NIGHT - (CEILINGS OF 200 FEET AND 100 FEET)

available facilities. For practical reasons ceiling is reported to the nearest hundred feet; hence official ceiling in Figs. 27 and 28 could be visualized as a band 100 feet thick rather than a straight line. It should be recognized that "conventional" methods of reporting give cloud height and visibility, and that at 400 feet altitude on the glide-slope the pilot has a potential slant visual range through more than a mile of atmosphere. ALCH techniques provide a reporting value to the pilot empirically based on pilot experience, with operational significance, of the approach lights.

It should be noted that the 50 per cent probability level of ALCH would in general fall about midway in the ALCH ranges illustrated in Figs. 27 and 28. Investigators have suggested that after a period of operational familiarization a pilot might feel more "comfortable" with a single ALCH probability value, particularly since his flight conditioning and experience could be more easily reconciled to one number. However, two probability values represent a more complete description of the possibilities of his response to the approach lighting and may represent a more valuable gage of the weather conditions he will encounter on his approach.

In Figs. 27 and 28 the official ceiling was actually observed at varying times prior to, but in effect at the time of approach light contact. Since no comprehensive ALCH observational program was conducted at Atlantic City, the ALCH values were those recomputed from meteorological data recorded at the instant of approach light contact. Observed ALCH values, such as those determined by an automatic computer about 2 minutes prior to light contact, would probably differ little from those shown in the figures.

## INVESTIGATION OF OPTIMUM INTENSITY OF APPROACH AND RUNWAY LIGHTS

### Background

The idealized approach and runway lighting system requires, primarily, that the illumination be of sufficient intensity to universally satisfy the demands of all pilots during the final stages of a low weather approach and landing, but at no time dazzle the pilot or otherwise decrease his effectiveness.

Solutions to the problem of optimum approach and runway light intensity have been sought for the last few decades, but significant results have been limited by the relatively inadequate state of airfield lighting and meteorological instrumentation, and also by the limited availability of sufficient experimental data. Of interest are the experiments at Nantucket and Indianapolis reported in 1945 (Reference 9), which resulted in a general formula for the optimum intensity of an approach light system for night use. While the formula thus developed was in contemporary terms of illumination and atmospheric transmission, the experimental method relied on fixed ground observers, and on a lighting configuration not currently used. Following this approach, photoelectric equipment was designed to automatically adjust the intensities of approach and runway lights to accommodate changes in atmospheric transmission and background brightness (Reference 10). Insufficient experimental data limited the application of the method. A working model of this system was tested in 1948 (Reference 11), and a conclusion reached at a later date that improvement should be made in the means of obtaining the proper intensity setting (Reference 12).

Current instructions for the operation of high-intensity approach lights provide wide discretionary latitude for the tower specialist, permitting the intensity of the lights to be based on a general visibility guide, modified by experience, pilot request, and local lighting configuration (Reference 13). The official approach light intensity guide indicates no specific intensity settings when visibility is below 1/4 mile. There is some ambiguity in the instructions regarding the location at which the visibility is to be determined. Similar instructions for the intensity settings of runway lights are not available. Guides are usually devised at the local level.

## General Discussion

The optimum intensity of approach and runway lights is related to a complex interplay of a considerable number of psycho-physical factors with respect to meteorological phenomena, pilot, aircraft, and photometry. Investigators in these various fields have stressed the importance of the individual elements in the general solution to the problem of optimum light intensity. The intention of this investigation was to collate the most signficant of the factors, and empirically design an optimum light intensity system effectively accommodating most variants to provide a simple basis for practical application. The existing mediums of ALCH and RVR provide a useful design basis for the desired system.

The factors have been considered in this manner:

1. Meteorological: This and previous investigations have recognized the difficulty of adequate sampling of ceiling and visibility. The middle marker area has been designated as the standard site for the RBC, and the instrument runway touchdown has usually been selected as the transmissometer site. Reported cloud heights are generally representative of those in the area of the aircraft when the pilot would have vertical contact at an altitude of 200 feet on the glide slope. Transmittance is determined by a transmissometer along a baseline quite small with respect to the existing visual range, and does not consider the variation in stratification of the obstruction to vision. In the ALCH/RVR concept, based on the present state of the art of meteorological instrumentation, the atmosphere is usually considered homogeneous, and the meteorological measurements as representative of the pilot's environment. An exception is the presence of low clouds which is discussed separately.

2. Pilot: Because of individualism, this is the most difficult parameter to measure with respect to physical and psychological condition, if indeed not indeterminate. While visual illuminance threshold $E_t$ is, in fact, a measure of the recognition of light, the manner in which project data have been acquired permits this to be a comprehensive term, particularly when inclusive values of $E_t$ at certain probability levels are established and used. In this manner those factors are readily absorbed which reflect considerable variation with time, space, and pilot, such as search time and brightness level adaptation.

3. Photometric: Previous investigations (Reference 5) have determined that the ratio of horizon luminance to terrain illumination

is virtually constant with varying terrain illumination, and is not considered a significant factor in the presence of high-intensity airfield lighting. The effect on the pilot of variations in background brightness is considered inherent in a high probability $E_t$, as well as to a limited extent in terrain illumination, which has been classified as day/night. No special consideration is made for the variations of terrain illumination since the data at Atlantic City indicated that this factor is the least significant of the variables measured, in the influence on the height of the aircraft at which the pilot had contact with the approach lights.

4. Aircraft: Cockpit cutoff angle is considered to be 15°. In general, such variations between aircraft as approach attitude, approach speed, cockpit lighting, and light absorption qualities of the windscreen have been included in the derivation of $E_t$.

5. Lights: The approach and runway light configurations used in this study are those that have been suggested by the FAA (References 6 and 7).

Many subjective considerations may have indeterminate significance in the problem of optimum light intensity. Pilots who have experience in poor weather approaches at a particular airfield will obtain many visual clues apart from approach and runway lights, and hence require less information. Discussions with pilots have revealed strong attitudes with respect to preference, opinion, and habit. Responses to inquiries have ranged from, "They're always too bright," to "When I'm coming in I want everything on that you've got." When viewed against the diffuse background of personal and, frequently dogmatic opinions, a discrete idealized optimum light intensity appears difficult to define adequately.

Another consideration in the approach to the problem is the determination of what point along the flight path shall the various lights be maintained as optimum. Aircraft flying high on the glide slope, or performing other than a straight-in approach, may be outside the most effective areas of the focused light beams. Ideal light intensity at the first point of sighting in a cloud deck is at once too bright when the aircraft descends below the base of the clouds into an area of good atmospheric transmission, and is particularly critical during the final stages of flight when the aircraft is in the immediate vicinity of the lights. The extent to which the approach lights will penetrate the cloud deck is quite variable, dependent primarily on the density and coverage of the strata (Figs. 29 and 30).

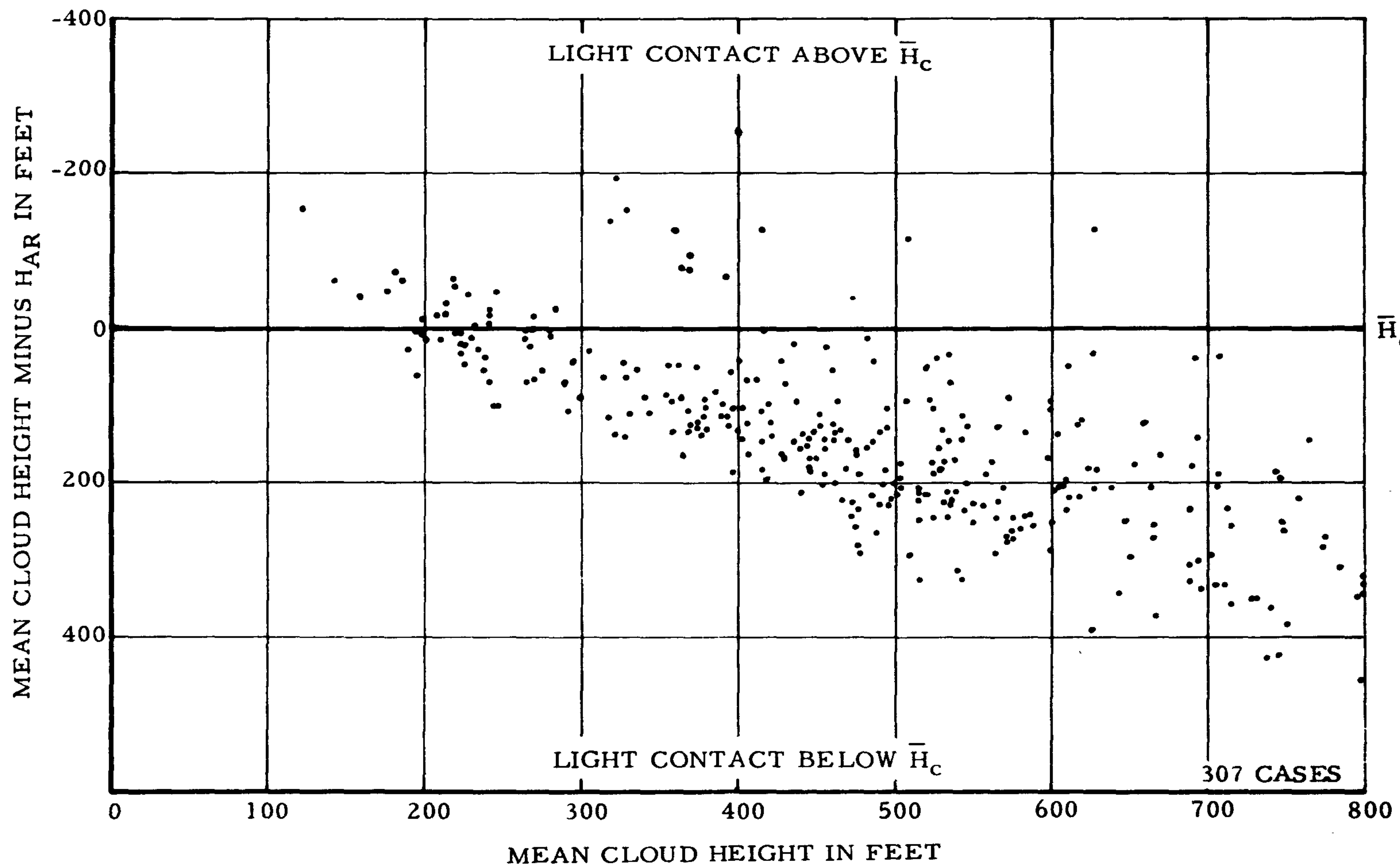



**FIG. 29 MEAN CLOUD HEIGHT ($\overline{H}_c$) VS. MEAN CLOUD HEIGHT ($\overline{H}_c$) MINUS $H_{AR}$ - DAY**

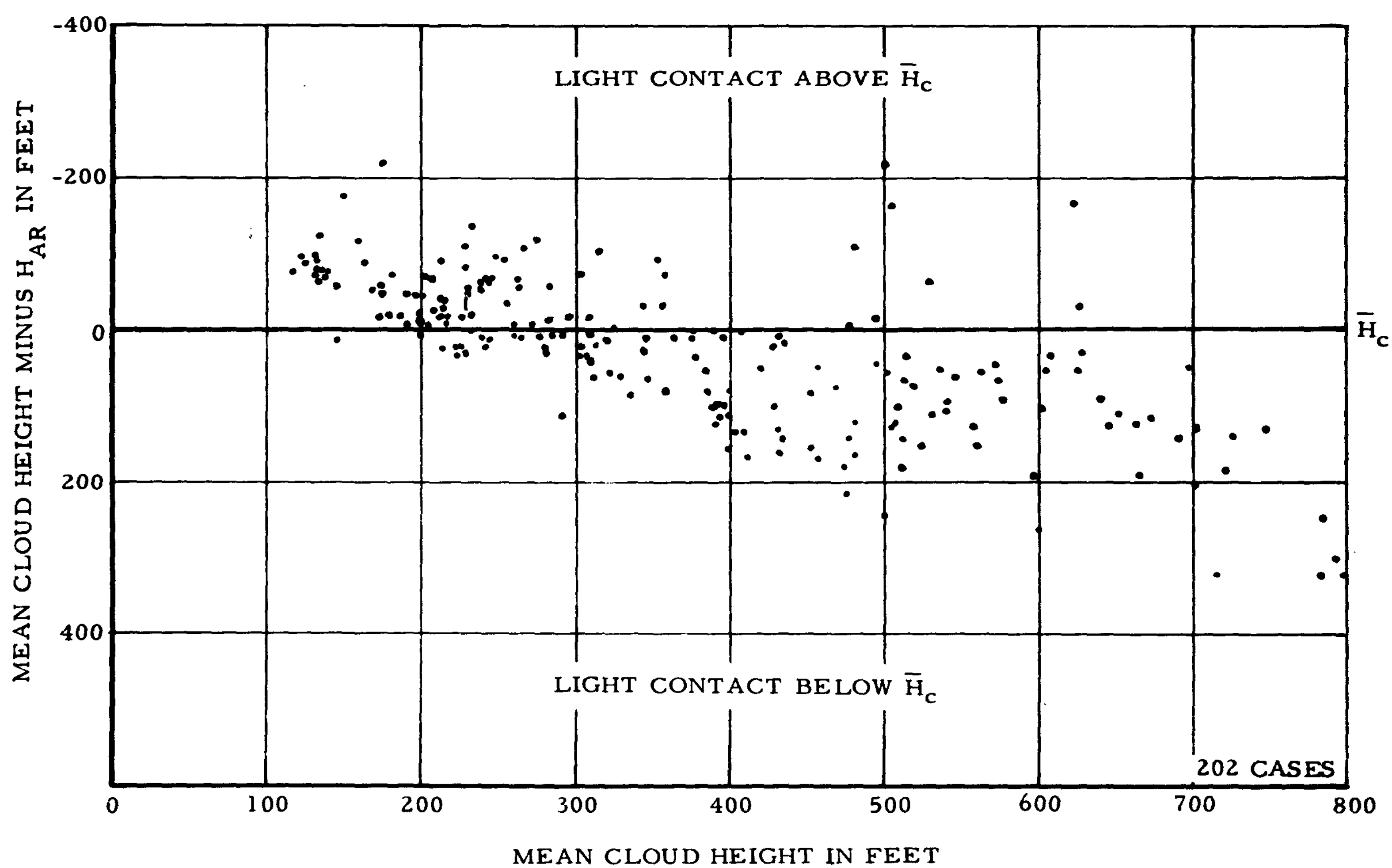



FIG. 30 MEAN CLOUD HEIGHT ($\overline{H}_c$) VS. MEAN CLOUD HEIGHT ($\overline{H}_c$) MINUS $H_{AR}$ - NIGHT

## Optimum Approach Light Intensity System

### 1. Discussion

An optimum approach light intensity system was designed about the concepts and assumptions of ALCH, when atmospheric transmission is the limiting factor to a pilot's visual range. These are discussed in detail in other portions of this report and in Reference 1. Of particular pertinence to this discussion are the factors of flight path, approach light configuration, and certain empirical constants. Further, to facilitate practical application of the system, optimum approach light intensity has been defined as that light intensity which will provide the pilot sufficient slant visual range to permit approach light contact at a minimum descent altitude of 200 feet along an approximate ILS glide slope flight path.

Optimum light intensity, as far as the pilot is concerned, is also a function of his $E_t$. This is a comprehensive term, and varies for a group of pilots under varying approach conditions and times and, in fact, for any one pilot. To accommodate this term and make the design of optimum light intensity most useful to the largest number of pilots, it was determined to utilize the probability of $E_t$ which provides ALCH$_{.9}$, $E_{t.9}$. The ALCH$_{.9}$ was held constant at 200 feet, with $T_{500}$ and I considered the variables. Dependent on a combination of transmittance and approach light intensity, this would, in effect, provide the pilot whose $E_t$ is at the 90 per cent probability level with at least 200 feet altitude on an ILS approach; approximately 90 per cent of the pilots under such control would, under the same meteorological conditions, have approach light contact at varying altitudes higher than 200 feet.

A limited amount of data approaches were available at Atlantic City from which $E_t$ could be derived, 39 night and 9 day. The adequacy and limitations of these data were discussed previously. The empirical constants determined at Atlantic City for pilot reports of the EFAS were

$$\text{Day,} \quad E_{t.9} = 1.977 \times 10^{-3} \text{ lumens ft.}^{-2} \tag{17}$$

$$\text{Night,} \quad E_{t.9} = .1191 \times 10^{-3} \text{ lumens ft.}^{-2} \tag{18}$$

These values were based on the corresponding $C_{.9}$ derivations.

A significant consideration in this investigation was the nature of the EFAS and steady-burning approach lights. This design is adapted to the approach lighting described in Reference 6. Technical details of the approach light system in use during the tests at Atlantic City are given in Table I.

Approach lights are generally oriented to permit the candlepower distribution to provide the maximum beam intensity in the immediate area of the ILS glide slope axis. The exact distribution is dependent on the intensity setting. However, the exact glide slope is not, in fact, the path of flight followed by most pilots during an instrument approach. Discussions with pilots and a review of data acquired at Atlantic City and Newark confirm the observation that most pilots tend to fly above the glide slope until visual contact is established during an ILS approach. Of the 50 test approaches made at Atlantic City when visibility was the prime factor, 64 per cent were above the official glide slope angle of 2.59 degrees when the pilot made initial contact with the approach lights. The angle of the line of best fit glide slope was derived from these data to be 2.69 degrees with a correlation coefficient of 0.840, (Fig. 26). Similar relationships were obtained at Newark. This glide slope was used as the basis for the minimum descent altitude of 200 feet.

Of interest was the effect of terrain illumination in the design of this optimum light system. This effect was discussed earlier with respect to the basic correlations of ALCH factors. Briefly, it has been observed at Atlantic City, as at Newark, that the level of illumination has little influence on $H_{AR}$, other factors held constant. Differences are apparent between day (Fig. 29), and night (Fig. 30), and are considered in the design of the system. The range of $E_g$ is quite limited in the type of weather for which optimum light intensity is required. For example, throughout the period that data were acquired at Atlantic City, the bulk of daytime low weather approaches were during $E_g$ conditions less than 1800 foot-candles. A midsummer day at these latitudes, with cloudless skies and visibility in excess of five miles, may have a maximum $E_g$ of about 10,000 foot-candles.

2. <u>System Design</u>

Since atmospheric transmission will be considered the most restrictive factor to the pilot's slant visual range in that portion of the approach path where the approach light intensity is to be optimum, Allard's Law is relevant. Solved for light target intensity, it is

$$I = \frac{E_t \, V^2}{(T_B)^{V/B}} \tag{19}$$

Equation (19) in logarithmic form is

$$\text{Log } I = -\frac{V}{B} \text{Log } T_B + \text{Log } E_t + 2 \text{ Log } V \qquad (20)$$

where $V \approx 1255$ feet on a line of best fit glide slope of 2.69°, from which a height of 200 feet on this glide slope is derived.

B = 500-foot transmissometer baseline,

T = percentage transmittance,

$E_{t_p}$ = (day): $E_{t.9} = 1.977 \times 10^{-3}$ lumens ft. $^{-2}$

(night): $E_{t.9} = 0.1191 \times 10^{-3}$ lumens ft. $^{-2}$, based on

effective EFAS intensity of 15,000 candlepower.

resultant I = optimum approach light intensity.

If $E_t$ and V are held constant, the equation for Log I is in the slope-intercept form and has been presented graphically in Fig. 31 as a straight line with slope -V/B. Based on the empirical constants introduced, Fig. 31 can be entered with transmittance and an optimum approach light intensity derived.

It is of interest to compare the optimum light intensities thus obtained with the official approach light intensity guide. During the day the optimum curve describes intensities generally lower than those suggested by the guide. At night, where the guide is content with an intensity of about 1000 candlepower even under the lowest visibility conditions, the optimum light curve provides for increasing intensities with decreasing visibilities.

3. System Limitations

In the development of this optimum approach light system, no separate consideration was made for those instances of very low clouds or shallow ground fog.

Acquired data indicate that very low overcasts are usually accompanied by low ground transmittances, or the low clouds themselves deteriorate into obscuration conditions. In these instances, the conservative aspects of $E_{t.9}$, within Allard's Law, are expected to assure basic

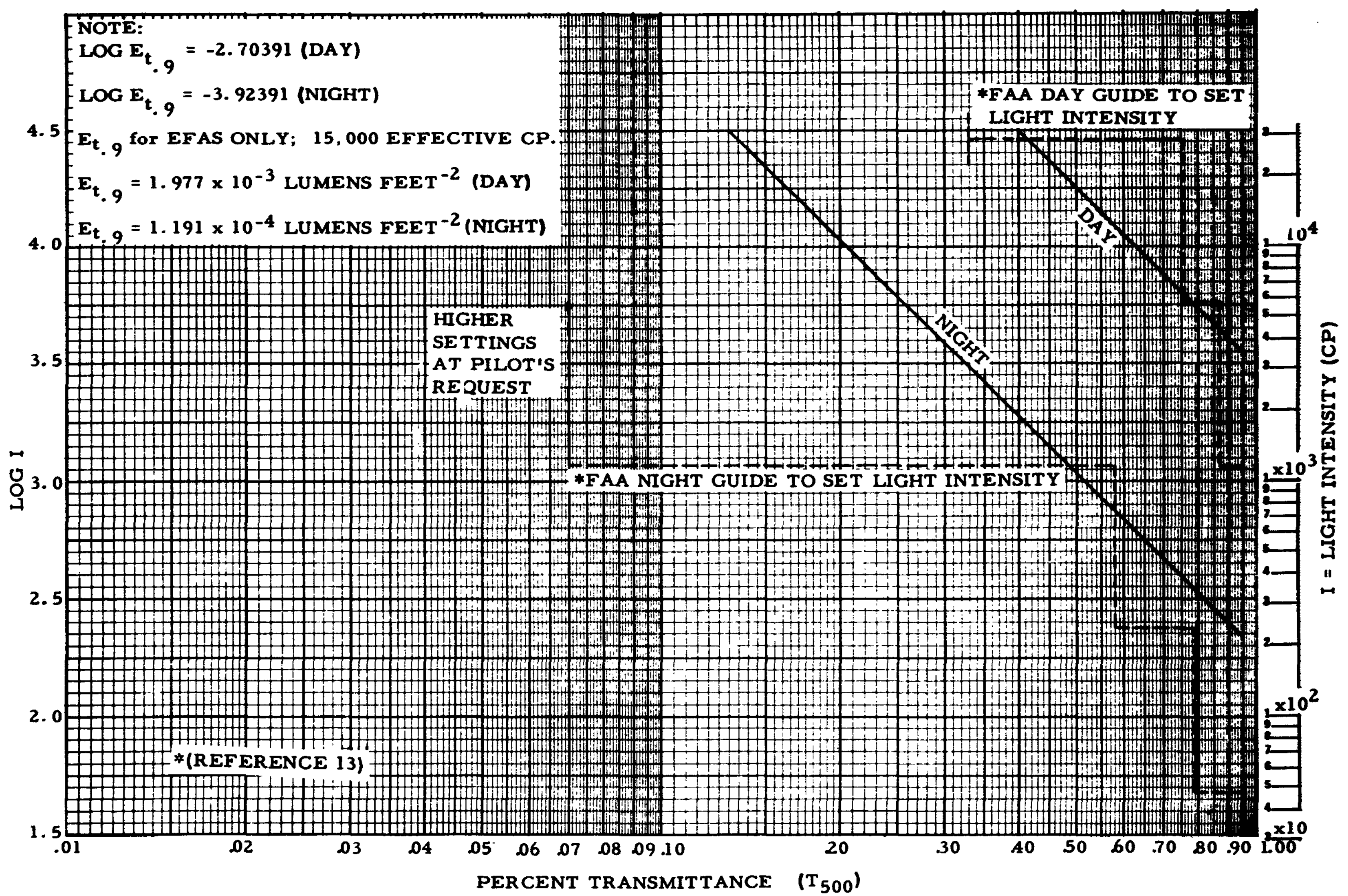



FIG. 31 OPTIMUM APPROACH LIGHT INTENSITY, BASED ON ALCH CONCEPT, PROVIDING MINIMUM DESCENT ALTITUDE OF 200 FEET, GLIDE SLOPE 2.69 DEGREES

validity of the design system. In some less frequently encountered cases, those of very low cloud bases and good ground transmittances, the conventional manner of sampling surface transmission might appear to decrease the effectiveness of the system design.

This deficiency is countered to some extent. Assuming the horizontal transmittance within the lowest layers of typical low clouds approaches .00, maximum light intensity is required to penetrate into the strata. Upon breakout, and in the presence of high atmospheric transmission, these maximum settings would at once be intolerably bright. It is therefore logical to base the operation of the steady burning approach lights on this design system with the condition that the EFAS be "on" as discussed in paragraph 4 following. Since the EFAS is not variable in intensity, the steady burning lights would be controlled to the extent that $ALCH_{.9}$ = 200 feet, utilizing primarily a visibility input. While the system cannot provide $ALCH_{.9}$ = 200 feet when very low clouds are the dominant visibility obstruction, it would avoid excessive brightness immediately after breakout, while the EFAS would provide a means of initial contact with the approach light array.

During shallow ground fog, the approach lights may be driven at too high an intensity, depending on the depth and density of the surface-based layer. The variation of these depths cannot be measured by current field meteorological instrumentation. Because low surface transmissions are usually present in these conditions, the conservative qualities of the design system are considered adequately applicable in the ground fog cases.

In the application of this system, some reservations must be made regarding the use of the transmissometer input during rapidly varying transmissivity conditions or in a non-homogeneous atmosphere. Since the system design is based on the current transmissometer design, and although there might be future improvement in instrumental design and field sensor location, the practicality of this optimum light design system could be limited during extreme transmittance conditions.

4. Design Operation

This suggested configuration is based on the approach lighting system described in Reference 6, including high intensity steady burning bar lights, and EFAS of 15,000 effective candlepower, as described in Table I.

a. The steady-burning approach lights should be operated as shown in Fig. 31 to provide guidance required for adequate approach perspective.

b. The EFAS should be on in the presence of clouds below 500 feet and/or transmittances below those required for operation of approach lights at intensities of 300 candlepower or greater, to provide guidance required for adequate recognition of the approach light array.

c. Manual override should be provided for emergency conditions or when weather anomalies appear to cause unrealistic system operation.

## Optimum Runway Light Intensity System

### 1. Discussion

The problem of optimum runway light intensity has been approached through the concepts and assumptions of RVR. RVR represents the horizontal distance a moving pilot will see down the runway from the approach end. It is based on the sighting of either high intensity runway lights or on visual contrast of other targets, whichever yields the greatest visual range. It is horizontal and not slant visual range, and is determined by the measurement of a transmissometer made near the touchdown point of the instrument runway, and a simple photometric switch which measures day/night.

RVR is provided at many airfields with the number of such installations increasing. It is the official minimum at many fields having specified navigational aids, for both takeoff and landing regardless of the reported ceiling and visibility. The specified minimums vary, but are usually 2000 feet or 2600 feet.

Since RVR is an accepted operational concept, the designated RVR constants have been utilized to provide a basis for the practical application of the system design. Further, optimum runway light intensity is defined as that light intensity which will provide the pilot with sufficient horizontal visual range to permit runway light contact at a specified minimum distance. Visual contrast of other targets will not be considered. For the purposes of this design 2000 feet and 2600 feet RVR is specified as the minimum distances.

As in the case of approach lights, $E_t$ is a sensitive factor. In this runway light consideration it has the same general meaning and includes the same indeterminate variables.

The RVR program stipulates certain $E_t$ values. They are:

Day, $E_t = 3.587 \times 10^{-5}$ lumens ft. $^{-2}$ (1000 mile-candles) (21)

Night, $E_t = 7.174 \times 10^{-8}$ lumens ft. $^{-2}$ (2 mile-candles) (22)

This optimum runway lighting system has been designed about a light target as described in Reference 7. The lights considered in the RVR concept are of the high intensity type with an accepted effective rating of 10,000 candlepower. A common runway light configuration is used at Atlantic City (Table XIII).

2. System Design

In the RVR concept atmospheric visibility is considered the only restrictive factor to the pilot's horizontal visual range during takeoff and the latter stage of a landing. Allard's Law is again relevant:

$$\text{Log } I = -\frac{V}{B} \text{ Log } T_B + \text{Log } E_t + 2 \text{ Log } V \qquad (20)$$

where: V = horizontal visual range (RVR) for which optimum light intensity is desired, in these cases 2000' and 2600',

B = 500' transmissometer baseline,

T = percentage transmittance,

$E_t$ =(day): $E_t = 3.587 \times 10^{-5}$ lumens ft. $^{-2}$,

(night): $E_t = 7.174 \times 10^{-8}$ lumens ft. $^{-2}$,

resultant I = optimum runway light intensity.

Figure 32 illustrates the optimum runway light intensities thus derived. As in the ALCH concept, RVR requires no consideration of terrain illumination in excess of the simple day/night relationship.

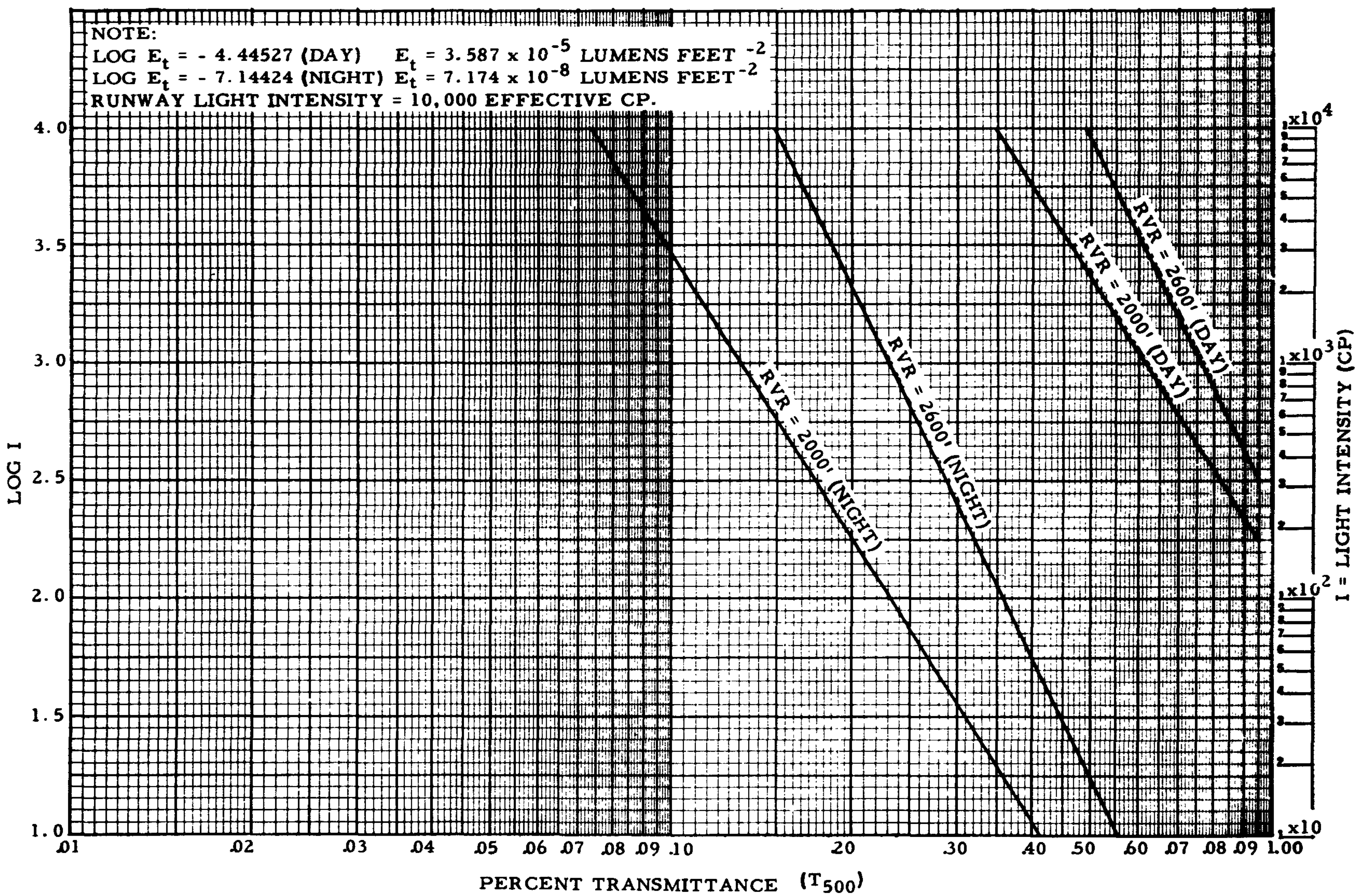



FIG. 32 OPTIMUM RUNWAY LIGHT INTENSITY, BASED ON RVR CONCEPT, PROVIDING MINIMUM RVR OF 2000 FEET OR 2600 FEET

## TABLE XIII

### LIGHT SETTINGS AND INTENSITIES FOR THE ATLANTIC CITY RUNWAY LIGHT SYSTEM

Runway 13-31

Type C-1 elevated runway marker light

Lamp: T-14 bulb, C-13 filament, 200 watts, 6.6 amperes,
29,000 peak candlepower, 12,000 representative candlepower.

Fixtures: MIL-L-5904B, 11 degree toe-in, first 2000' runway 13,
MIL-L-5904, 4 degree toe-in, last 8000' runway 13.

Regulators: Type AN-2557-4, first 7000' runway 13

| Step | Factor of Maximum Intensity |
|---|---|
| 1 | 0.01 |
| 2 | 0.03 |
| 3 | 0.10 |
| 4 | 0.30 |
| 5 | 1.00 |

Type NC-3, last 3000' runway 13

| Step | Factor of Maximum Intensity |
|---|---|
| 1 | 0.0016 |
| 2 | 0.008 |
| 3 | 0.04 |
| 4 | 0.20 |
| 5 | 1.00 |

See reference 7.

3. System Limitation

Because the same instrumentation is used to determine transmittance for this light system design as is used in the optimum approach light intensity system, the limitations with respect to shallow ground fog and extremes in transmissivity conditions apply here as well.

4. Design Operation

This suggested operation is based on the runway light system described in Reference 7, utilizing high-intensity lamps described in Table XIII.

a. The runway lights should be operated as shown in Fig. 32 to provide adequate runway visual range during the latter landing and initial takeoff stages.

b. A manual override should be provided for emergency conditions or when weather anomalies appear to cause unrealistic system operation.

## INVESTIGATION OF THE VARIATION OF TRANSMITTANCE ALONG A RUNWAY

### Background

The measurement of atmospheric transmission, in common with many similar measurements in the physical sciences, sometimes has an uncertain validity because of the limitations in obtaining a representative sample of the natural phenomena. Since it has been observed that transmission may vary radically with time and space, there is concern regarding the applicability of RVR determined from a transmissometer located at the touchdown area, to landing roll and takeoff operations. Figure 33, a record of one hour of transmittance measured by four transmissometers along NAFEC's runway 13-31, substantiates this concern.

The situation illustrated in Figure 33 is not an infrequent occurrence; meteorologists and air traffic specialists can often recall instances when one end of a runway was obscured by fog while other areas were clear. However, when RVR is determined by the transmissometer operating over a relatively short, finite baseline, differences of this type may not be adequately detected for operational purposes.

To adequately examine the problem of instrumental site applicability, a series of basic studies in variations of transmittance and RVR were prepared and statistically investigated. Since a pilot receives RVR as a nearly instantaneous value (Weather Bureau RVR computers present a nominal 1-minute average) rather than as a mean of visibility for an extended period, it was decided to approach the problem by examining instantaneous values at fixed five-minute intervals, and thus include in the data series a random sampling of extreme fluctuations in transmittance that might occur.

### Instrumentation

Four transmissometers were installed along runway 13-31 as shown in Fig. 2 and designated as: Transmissometer 1 (T1), threshold runway 13; Transmissometer 2 (T2), touchdown runway 13; Transmissometer 3 (T3), midpoint runway 13-31; and Transmissometer 4 (T4), touchdown runway 31.

The theory and design of the transmissometer system are thoroughly discussed in References 14 and 15. Briefly, the system

LEGEND

| | | |
|---|---|---|
| •••••••• | TRANSMISSOMETER ONE | ($T_1$) |
| IIIIIIIII | TRANSMISSOMETER TWO | ($T_2$) |
| – – – – | TRANSMISSOMETER THREE | ($T_3$) |
| ——— | TRANSMISSOMETER FOUR | ($T_4$) |

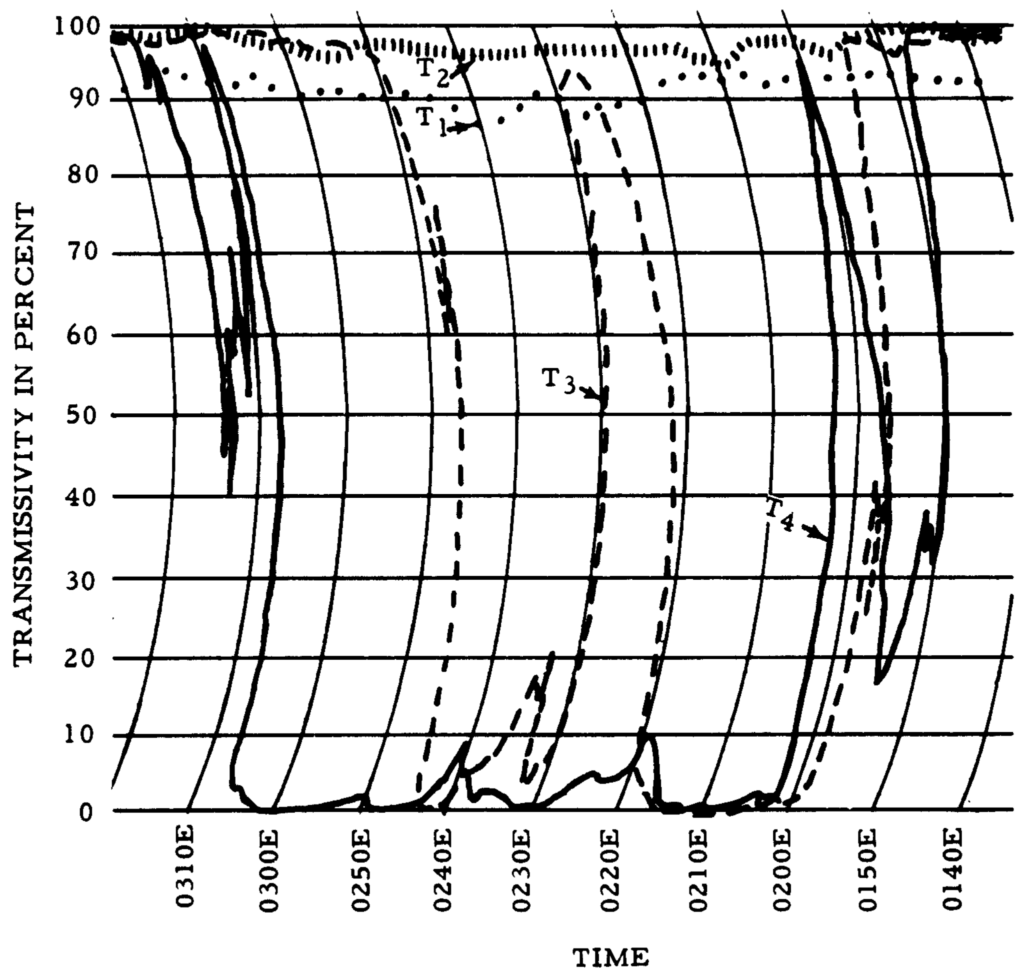



FIG. 33 AN EXAMPLE OF TRANSMITTANCE VARIATIONS BETWEEN FOUR ADJACENT TRANSMISSOMETER SITES OCTOBER 13, 1960

measures the transmission of light through the atmosphere along a designated baseline, 500 feet being used at NAFEC. The transmittance thus measured is nondirectional, and while in a strict sense can only be applied to the area sampled is, in practice, applied to larger geographical dimensions by assuming the sample is representative of a homogeneous atmosphere. Conversion of transmittance to other functional entities, such as RVR and meteorological visibility, is based on day and night classes and certain derived calibration constants.

As a supplement to the transmittance data obtained from the transmissometer installation, wind speed and direction at 20 feet above ground was recorded at T3.

Data Acquisition and Reduction

Simultaneous recordings of transmittance at the four sites were begun August 19, 1960, and concluded March 14, 1961. Other data considered in these studies were day/night class, and official prevailing meteorological visibility.

To insure timing accuracy, all recorders included chronograph pens which marked five-minute intervals received as a signal from the master timing system.

The continuous operation of the four systems permitted the project to acquire a large number of transmissometer recordings. As might be expected, only a fraction of the recordings were for low visibility conditions. Periods of transmittances for longer than one hour below $T_{500} = 0.75$, night or day, were considered a data group to be further analyzed. This requirement had only to be satisfied by one transmissometer to require analysis of the records at all four sites. If the basic hour selected on one system was contiguous with a period of low transmittance on another, the larger combined period was analyzed.

Utilizing a semiautomatic oscillograph amplitude tabulator, the transmissometer strip chart records were reduced to instantaneous transmittance at discrete five-minute intervals. These entries were then placed on data punch cards to facilitate statistical analysis by the NAFEC computer.

## Investigations

### Study 1

A difficult consideration in the RVR concept is the establishment of a transmissometer site that would provide valid information at all stages of landing and takeoff. Currently, at airfields which have one ILS runway, the transmissometer is usually located at touchdown. In addition to providing RVR information during landing roll, this same instrumental site is used to determine RVR during takeoff operations although wheels-off will take place at the opposite end of the runway. A related difficulty is adequate instrumental siting at airfields with a multi-ILS runway complex.

To examine the problem of a representative transmissometer site at which to measure RVR, Study 1 was instituted: When RVR at a specified transmissometer location is equal to, or greater than the airfield minimum, what percentage of those instances is RVR less than the airfield minimum at the other three transmissometer locations? Conversely, when RVR is less than the airfield minimum at a specified transmissometer location, what percentage of those instances is RVR equal to or greater than the minimum at the other three transmissometer sites?

For purposes of these studies, minimum RVR has been defined as 2000 feet. In instrumental terms: day $T_{500} = 0.346$; night $T_{500} = 0.073$; effective runway light intensity 10,000 candlepower.

Table XIV lists those instances where RVR at a specified location is less than 2000 feet, while the other transmissometers record an RVR equal to, or greater than 2000 feet at the same time. In these occurrences disagreements between transmissometers can be noted. This is particularly true of T1 and T4, and T2 and T4, the units situated farthest apart. This table further indicates that when RVR is based on touchdown T2, the values disseminated cannot be expected to be representative of the visibility situation the pilot may encounter during the landing roll, or latter stages of takeoff. A review of the data clearly indicates that in the most critical instances, when a specified transmissometer indicates RVR values less than the airfield minimum, that unit does not necessarily typify RVR at the other sites.

In the converse, less operationally critical situation, where RVR at a particular site is in excess of 2000 feet, there is less variation at the three other sites with respect to the minimum RVR (Table XV).

## TABLE XIV

When RVR at the specified transmissometer site is <u>less</u> than an airfield minimum of 2000 feet, the percentage of those occurrences that the other transmissometers indicate <u>equal to or greater</u> than 2000 feet RVR.

| | NIGHT | | | DAY | | |
|---|---|---|---|---|---|---|
| | Total Occurrences | No. of Occurrences | Percentage of Occurrences | Total Occurrences | No. of Occurrences | Percentage of Occurrences |
| When T1 $<$ 2000 feet RVR: | 274 | | | 157 | | |
| T2 $\geq$ 2000 feet RVR: | | 31 | 11.3 | | 4 | 2.5 |
| T3 $\geq$ 2000 feet RVR: | | 29 | 10.6 | | 26 | 16.6 |
| T4 $\geq$ 2000 feet RVR: | | 54 | 19.7 | | 42 | 26.8 |
| a When T2 $<$ 2000 feet RVR: | 284 | | | 168 | | |
| T1 $\geq$ 2000 feet RVR: | | 41 | 14.4 | | 15 | 8.9 |
| T3 $\geq$ 2000 feet RVR: | | 37 | 13.0 | | 33 | 19.6 |
| T4 $\geq$ 2000 feet RVR: | | 55 | 19.4 | | 47 | 28.0 |
| When T3 $<$ 2000 feet RVR: | 321 | | | 143 | | |
| T1 $\geq$ 2000 feet RVR: | | 76 | 23.7 | | 12 | 8.4 |
| T2 $\geq$ 2000 feet RVR: | | 74 | 23.1 | | 8 | 5.6 |
| T4 $\geq$ 2000 feet RVR: | | 64 | 19.9 | | 22 | 15.4 |
| When T4 $<$ 2000 feet RVR: | 319 | | | 149 | | |
| T1 $\geq$ 2000 feet RVR: | | 99 | 31.0 | | 34 | 22.8 |
| T2 $\geq$ 2000 feet RVR: | | 90 | 28.2 | | 28 | 18.8 |
| T3 $\geq$ 2000 feet RVR: | | 62 | 19.4 | | 28 | 18.8 |

TABLE XV

When RVR at the specified transmissometer site is equal to or greater than an airfield minimum of 2000 feet, the percentage of those occurrences that the other transmissometers indicate less than 2000 feet RVR.

| | NIGHT | | | DAY | | |
|---|---|---|---|---|---|---|
| | Total Occurrences | No. of Occurrences | Percentage of Occurrences | Total Occurrences | No. of Occurrences | Percentage of Occurrences |
| When T1 ≥ 2000 feet RVR: | 852 | | | 400 | | |
| T2 < 2000 feet RVR: | | 41 | 4.8 | | 15 | 3.7 |
| T3 < 2000 feet RVR: | | 76 | 8.9 | | 12 | 3.0 |
| T4 < 2000 feet RVR: | | 99 | 11.6 | | 34 | 8.5 |
| a When T2 ≥ 2000 feet RVR: | 842 | | | 389 | | |
| T1 < 2000 feet RVR: | | 31 | 3.7 | | 4 | 1.0 |
| T3 < 2000 feet RVR: | | 74 | 8.8 | | 8 | 2.1 |
| T4 < 2000 feet RVR: | | 90 | 10.7 | | 28 | 7.2 |
| When T3 ≥ 2000 feet RVR: | 805 | | | 414 | | |
| T1 < 2000 feet RVR: | | 29 | 3.6 | | 26 | 6.3 |
| T2 < 2000 feet RVR: | | 37 | 4.6 | | 33 | 8.0 |
| T4 < 2000 feet RVR: | | 62 | 7.7 | | 28 | 6.8 |
| When T4 ≥ 2000 feet RVR: | 807 | | | 408 | | |
| T1 < 2000 feet RVR: | | 54 | 6.7 | | 42 | 10.3 |
| T2 < 2000 feet RVR: | | 55 | 6.8 | | 47 | 11.5 |
| T3 < 2000 feet RVR: | | 64 | 7.9 | | 22 | 5.4 |

Study 2

The usual practice is to locate a transmissometer at the touchdown zone of the ILS runway. When airfield minimums are based on RVR, this instrument is the controlling factor in the airfield acceptance and departure rate. If a requirement is established that there be only one transmissometer for each instrument runway, it is of interest to determine if T1, T3, or T4 locations would be representative of the currently acceptable T2 locations, in terms of RVR minimums. Section a of Tables XIV and XV furnish an answer. For example, at night the use of a mid-runway transmissometer (T3) would have permitted traffic 13 per cent of the time that the touchdown transmissometer was below minimums and restricted traffic 8.8 per cent of the time the touchdown transmissometer was above minimums.

These same tables illustrate the increased ability of the airfield to accommodate a greater measure of traffic if runway 13-31 were a dual ILS complex, with a touchdown transmissometer operative at each end. Airfield utilization could have been significantly increased by deeming the active area as the one with the most favorable RVR excluding, of course, other limiting factors such as wind.

Study 3

Runway visual range provides an additional operating minimum at airfields equipped with specified navigational aids for takeoffs and landings, regardless of the reported ceiling and visibility. Study 3 was prepared to examine the effect on airfield utilization when RVR was the controlling factor, as compared to the use of prevailing visibility, for designating the airfield "open" or "closed." The basic considerations were: When RVR is obtained from the conventional locations of touchdown, what proportion of the time is the touchdown transmissometer recording RVR....:

a... $\geq$ minimum while prevailing meteorological visibility is $<$ minimum,

b... $<$ minimum while prevailing meteorological visibility is $\geq$ minimum,

c... $<$ minimum while prevailing meteorological visibility is $<$ minimum.

For purposes of this study, minimums are considered as 1/2 mile for prevailing meteorological visibility, and 2000 feet based on maximum runway light intensity for RVR. Prevailing meteorological visibility, a common component of all aviation weather observations, is defined as the greatest visibility that exists over half or more of the horizon circle. Low visibilities, such as those under consideration here, are usually observed from the airfield traffic control tower. T2 and T4, both located at a runway touchdown zone, were treated separately as controlling transmissometers for RVR purposes.

Tables XVI and XVII reveal the effect on airfield utilization when minimums are based on RVR determined from a touchdown transmissometer, compared to prevailing meteorological visibility. The data substantiates the prevalent assumption that an airfield is more frequently closed when conventional visibility is used, than when RVR is the determinant factor. The effective gain in airfield utilization is substantial for those instances where RVR minimums were used for day and night, as well as for the two separate considerations of touchdown transmissometers. In these cases the gain ranged from 26 per cent to 39 per cent.

Not considered pertinent in these studies were the relative merits of RVR and conventional visibility with respect to accuracy or representation of conditions in any specific field location, nor the effects of low clouds on the airfield traffic flow.

Study 4

Of concern in aircraft operation is the effect on a pilot of rapidly varying visual range during landings and takeoffs. During these operations the aircraft is in rapid movement on the runway for only brief periods, and the problem relates to variations of visibility with space rather than time. These fluctuations occur frequently in nature, and can have wide magnitudes. While not confined to only one meteorological condition, they are typical of patchy fog, the condition for which RVR determined at one site is least representative at any other site.

TABLE XVI

THE EFFECT OF RVR MINIMUMS AND PREVAILING METEOROLOGICAL VISIBILITY MINIMUMS ON AIRFIELD UTILIZATION

RVR determined from Runway 13 touchdown transmissometer (T2)

| Condition (order of controlling factor) | | (a) Number of occurrences stated condition existed | (b) Total number of occurrences below minimums caused by RVR, visibility, or both | (a)/(b) Percentage of Occurrence |
|---|---|---|---|---|
| | | | DAY | |
| Visibility $< 1/2$ mi. | RVR $\geq$ 2000 feet | 132 | 339 | 38.9 |
| Visibility $\geq 1/2$ mi. | RVR $<$ 2000 feet | 12 | 339 | 3.5 |
| Visibility $< 1/2$ mi. | RVR $<$ 2000 feet | 195 | 339 | 57.6 |
| | | 339 | Gain using T2 RVR minimum rather than prevailing meteorological visibility - - - | 35.4 |
| | | | NIGHT | |
| Visibility $< 1/2$ mi. | RVR $\geq$ 2000 feet | 311 | 696 | 44.7 |
| Visibility $\geq 1/2$ mi | RVR $<$ 2000 feet | 102 | 696 | 14.7 |
| Visibility $\leq 1/2$ mi. | RVR $<$ 2000 feet | 283 | 696 | 40.6 |
| | | 696 | Gain using T2 RVR minimum rather than prevailing meteorological visibility - - - | 30.0 |

TABLE XVII

THE EFFECT OF RVR MINIMUMS AND PREVAILING METEOROLOGICAL VISIBILITY MINIMUMS ON AIRFIELD UTILIZATION

RVR determined from Runway 31 touchdown transmissometer (T4)

| Condition (order of controlling factor) | | (a) Number of occurrences stated condition existed | (b) Total number of occurrences below minimums caused by RVR, visibility, or both | (a)/(b) Percentage of Occurrence |
|---|---|---|---|---|
| | | | DAY | |
| Visibility < 1/2 mi. | RVR ≥ 2000 feet | 128 | 295 | 43.4 |
| Visibility ≥ 1/2 mi. | RVR < 2000 feet | 13 | 295 | 4.4 |
| Visibility < 1/2 mi. | RVR < 2000 feet | 154 | 295 | 52.2 |
| | | 295 | Gain using T4 RVR minimum rather than prevailing meteorological visibility - - - | 39.0 |
| | | | NIGHT | |
| Visibility < 1/2 mi. | RVR ≥ 2000 feet | 293 | 658 | 44.5 |
| Visibility ≥ 1/2 mi. | RVR < 2000 feet | 122 | 658 | 18.5 |
| Visibility < 1/2 mi. | RVR < 2000 feet | 243 | 658 | 37.0 |
| | | 658 | Gain using T4 RVR minimum rather than prevailing meteorological visibility - - - | 26.0 |

Study 4 has been developed to examine the frequency of differences in runway visual range between transmissometer locations at the same instant of time, and in the presence of wide transmittance variations. It is assumed in this study that the aircraft is in a landing or takeoff operation along runway 13-31 with a heading of 130 degrees.

Tabulations were made, when movement was considered along the runway as indicated, of all cases that RVR was lower at the same time at succeeding locations by at least 1000 feet.

Two data classes were considered: When the lower RVR at the succeeding transmissometer was $\leq$ 5000 feet and when the lower RVR at the succeeding transmissometer was <2000 feet.

Tables XVIII and XIX list the results of this study. The magnitude of the ratio of occurrences of the stipulated visibility departure, to the total sample, is of course governed by the upper limit of data acquisition, a transmittance of 0. 75. Considering this limitation, the ratios are moderately large, and would be larger, particularly in class b, if a lower data acquisition limit had been fixed. The ratios vary in proportion to the distance between transmissometers, an indication that the RVR derived from a specific transmissometer becomes less representative the farther an aircraft moves from the runway area being sampled.

<u>Study 5</u>

To examine the applicability of RVR determined from a touchdown transmissometer, to landing roll and takeoff operation, it was decided to investigate the frequency of maximum differences ($T_{max}$-$T_{min}$) between any two transmissometers at the same time.

The acquired data were stratified, for identical times, in the following manner:

a. Night, $RVR_{T_{min.}} < 2000$ feet

b. Day, $RVR_{T_{min.}} < 2000$ feet

c. Night, 2000 feet $\leq RVR_{T_{min.}} \leq$ 5000 feet

d. Day, 2000 feet $\leq RVR_{T_{min.}} \leq$ 5000 feet

TABLE XVIII

Assuming aircraft landing or takeoff operations, heading 130°, the frequency succeeding transmissometers along runway 13-31 will at the same time have a runway visual range lower by at least 1000 feet.

Class (a) When the lower runway visual range was $\leq$5000 feet

| Aircraft Movement From | Ratio of Occurrences to total data acquired | Percent | Aircraft Movement From | Ratio of Occurrences to total data acquired | Percent |
|---|---|---|---|---|---|
| | DAY | | | NIGHT | |
| T1 to T2 | $\frac{10}{640}$ | 1.56 | T1 to T2 | $\frac{76}{1314}$ | 5.78 |
| T1 to T3 | $\frac{19}{623}$ | 3.05 | T1 to T3 | $\frac{151}{1234}$ | 12.24 |
| T1 to T4 | $\frac{44}{606}$ | 7.26 | T1 to T4 | $\frac{214}{1189}$ | 18.00 |
| T2 to T3 | $\frac{16}{668}$ | 2.40 | T2 to T3 | $\frac{130}{1414}$ | 9.19 |
| T2 to T4 | $\frac{40}{651}$ | 6.14 | T2 to T4 | $\frac{200}{1364}$ | 14.66 |
| T3 to T4 | $\frac{17}{694}$ | 2.45 | T3 to T4 | $\frac{119}{1404}$ | 8.48 |

TABLE XIX

Assuming aircraft landing or takeoff operations, heading 130°, the frequency succeeding transmissometers along runway 13-31 will at the same time have a runway visual range lower by at least 1000 feet.

**Class (b) When the lower runway visual range <2000 feet.**

| Aircraft Movement From | Ratio of Occurrences to total data acquired | Percent | Aircraft Movement From | Ratio of Occurrences to total data acquired | Percent |
|---|---|---|---|---|---|
| | DAY | | | NIGHT | |
| T1 to T2 | $\frac{5}{640}$ | .78 | T1 to T2 | $\frac{14}{1314}$ | 1.07 |
| T1 to T3 | $\frac{12}{623}$ | 1.93 | T1 to T3 | $\frac{58}{1234}$ | 4.70 |
| T1 to T4 | $\frac{31}{606}$ | 5.12 | T1 to T4 | $\frac{69}{1189}$ | 5.80 |
| T2 to T3 | $\frac{10}{668}$ | 1.50 | T2 to T3 | $\frac{59}{1414}$ | 4.17 |
| T2 to T4 | $\frac{26}{651}$ | 3.99 | T2 to T4 | $\frac{61}{1364}$ | 4.47 |
| T3 to T4 | $\frac{6}{694}$ | .86 | T3 to T4 | $\frac{46}{1404}$ | 3.28 |

Classes a and b constitute Fig. 34. Here the data have been grouped in 4 per cent increments of $T_{max} - T_{min}$. Classes c and d are portrayed in Fig. 35; data grouped in 8 per cent increments of $T_{max} - T_{min}$. As can be seen, the differences between any two transmissometers at the same time, under the conditions specified, can be considerable, which decreases confidence in the application of RVR from a single transmissometer to landing roll and takeoff.

Limitation of Applicability of Studies

It is accepted that the details of all studies described are unique to runway 13-31 at Atlantic City because of inherent characteristics in instrumentation and climatic influences. However, it is considered a valid assumption that the general results of the studies can, in most cases, be applied to pertinent transmissometer problems at other airfields. With that assumption, the conclusions made on the basis of these results are considered equally valid to airfields that are not unusual with respect to meteorological sampling.

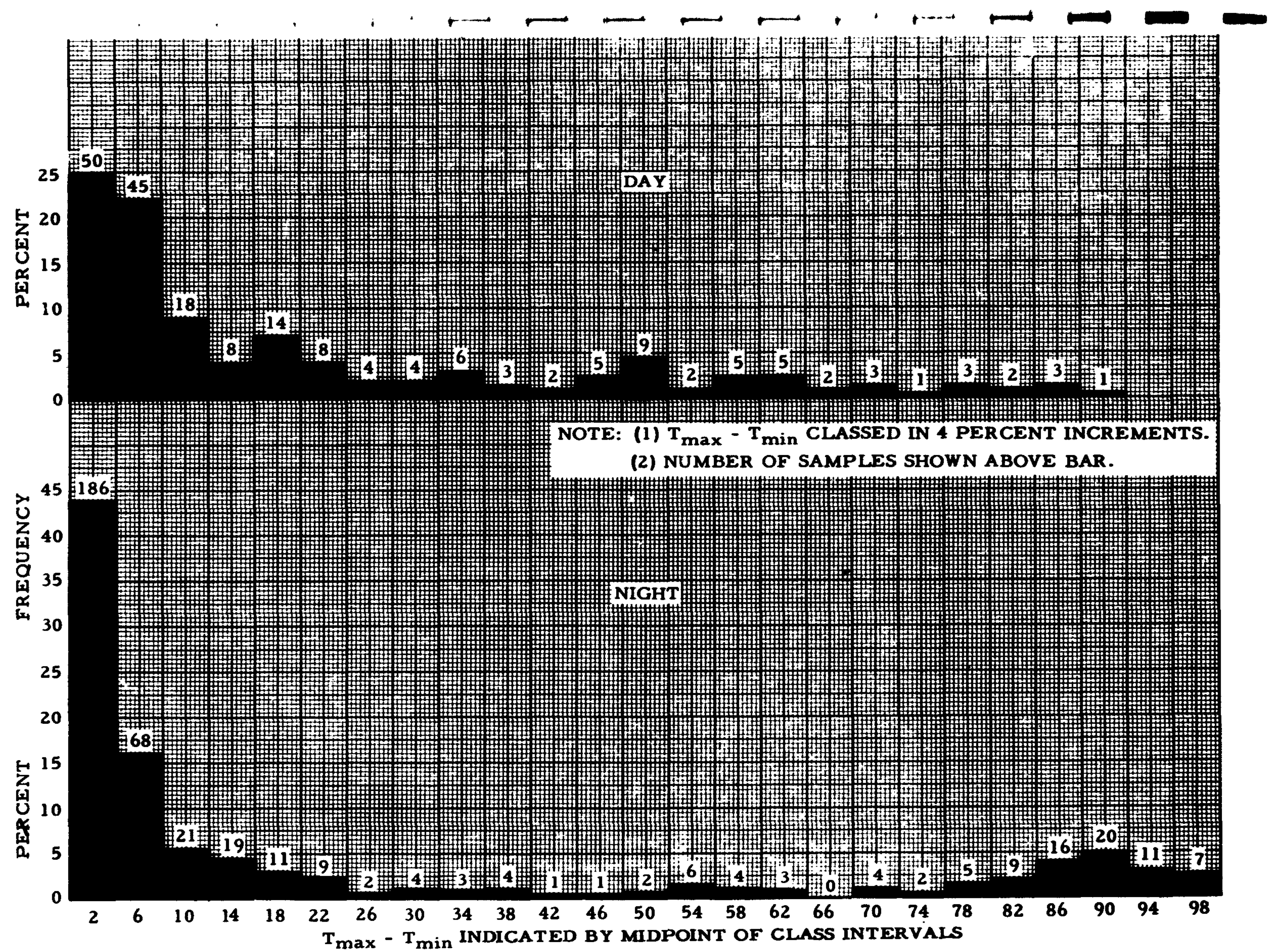



FIG. 34 MAXIMUM ABSOLUTE DIFFERENCES ($T_{max}$ - $T_{min}$) BETWEEN ANY TWO TRANSMISSOMETERS AT ANY ONE TIME WHEN RVR $<$ 2000 FEET

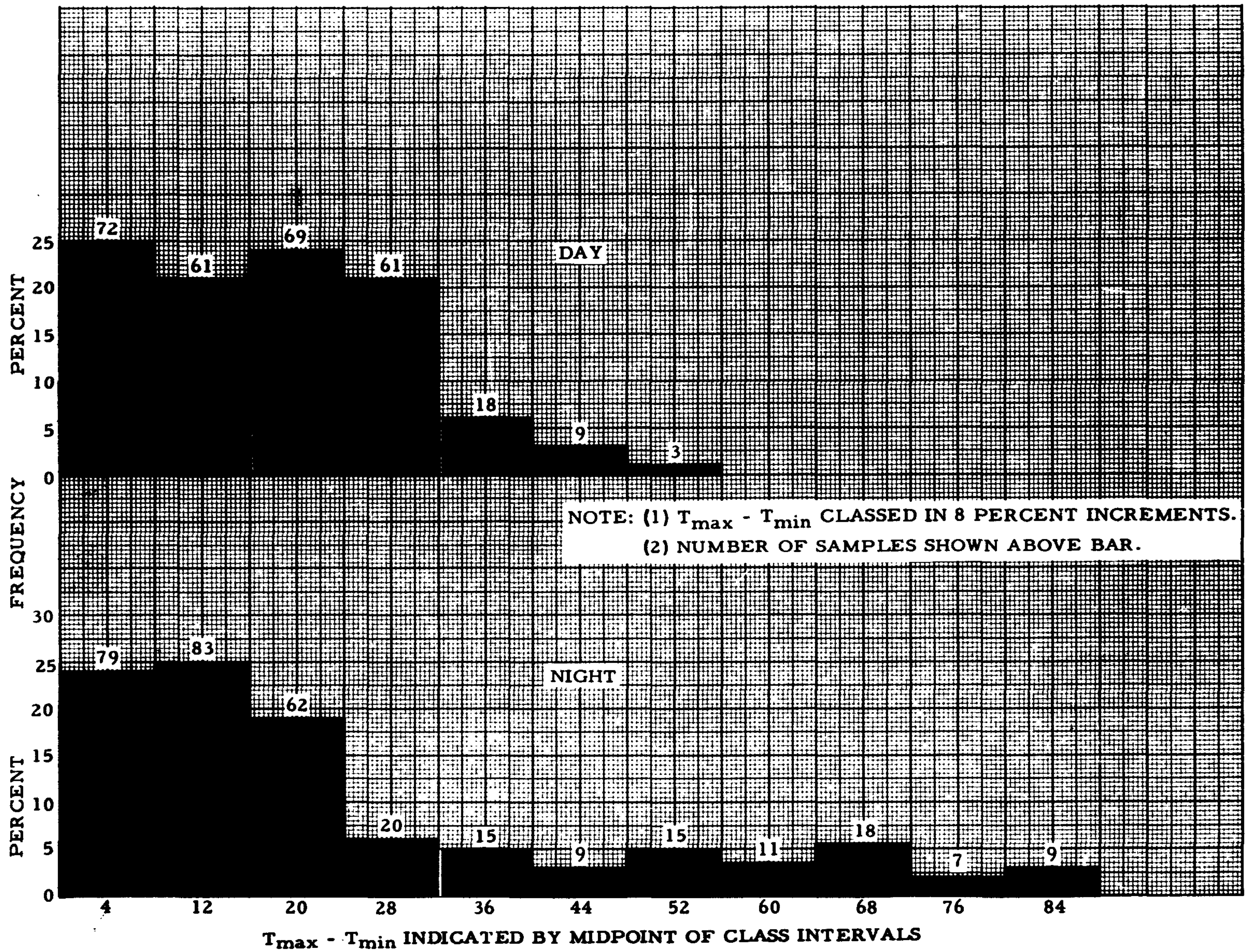



FIG. 35 MAXIMUM ABSOLUTE DIFFERENCES ($T_{max}$ - $T_{min}$) BETWEEN ANY TWO TRANSMISSOMETERS AT ANY ONE TIME WHEN 2000 FEET $\leq RVR_{T_{min}} \leq$ 5000 FEET

## AN ATTEMPT TO ELIMINATE THE INTERFERENCE TO THE ROTATING-BEAM CEILOMETER INDICATOR CAUSED BY THE ELECTRONIC FLASHING APPROACH LIGHTS

### Description of RBC System

The rotating-beam ceilometer (RBC) is a cloud-height measuring device considered a standard operational instrument. It features simplicity of design and operation, ease of installation, and rapid frequency of measuring cycles; measurements made every six seconds. The complete system consists of a projector, detector, indicator, and at a number of weather stations, a recorder. Complete details of the system, from which the following material has been adapted, can be obtained from Reference 16.

The projector consists of two identical optical systems situated in a 180° relationship on a rotary mount such that the projected light beams are continuously rotated in the plane of the detector's beam of receptivity. At some point in the rotation, each portion of the detector's beam of receptivity, from the top of the detector to the zenith, is illuminated. Any cloud or other reflective obstruction such as fog strata will cause a spot of light to occur as the light beams pass. Since the projected beam is modulated at 120 cycles, the detector photocell and amplifier, fix-tuned to that frequency, will produce a signal voltage corresponding to the intensity of the spot on the clouds.

The major portions of the detector are the optical system and amplifier. The optical system of the detector is directed to the zenith. It is adjusted so that light, parallel to the optical axis of a reflector, striking the reflector will converge at a lead sulphide photocell after passing through an infrared filter. The amplifier is a high-gain, low-noise, resistance-coupled amplifier, fix-tuned to approximately 120 cycles. The photocell is a lead sulphide cell of the photoconductive type.

The indicator consists of a cathode-ray tube with appropriate electronic and mechanical circuits. The electron beam of the cathode-ray tube moves up the vertical axis in synchronism with the rotation of the projector. When an amplified cloud signal from the detector is fed to the indicator cathode-ray tube, it causes the electron beam to widen momentarily as the beam moves up the face of the tube. The point at which the electron beam widens corresponds to the angle of the projected light beam when it strikes the cloud above the detector. The face of the indicator is calibrated in degrees corresponding to the angle of the light

beam; this angle can readily be converted into height by reference to tables pre-computed on the basis of the relative spacing of the projector and detector on a baseline.

The recorder is of facsimile type. The horizontal motion of the stylus is synchronized with the rotation of the projected light beam, and the density of the record varies directly with the strength of the reflected light signal. The recorder includes circuitry designed to eliminate the flashing approach light interference, but it has been the experience of the project staff that this feature is not always effective.

Description of Problem

There are two classifications of noise voltages encountered in the ceilometer systems:

a. The noise voltages due to changes in ambient light intensity received by the photocell, as well as noise in the cell itself, are inherent in this equipment and is usually of random phase and magnitude. Little can or need be done to remedy this problem which is usually of minor consequence.

b. Other noise voltages, due to line pickup, nearby strong modulated lights, and similar causes, are usually of fixed phase and of a frequency that will cause a continuous reaction of the indicator. These voltages must be eliminated if satisfactory operation of the RBC is to be obtained. Of concern to this investigation are the noise voltages introduced into the ceilometer system by the EFAS.

At most airfields where the RBC is in use, the middle marker has usually been selected as the RBC site for measuring the cloud bases. However, it is there that the ceilometer is particularly exposed to the output of the EFAS. A typical RBC installation is that at Atlantic City (Figs. 6 and 7).

The EFAS are composed of gaseous flash tubes, typically Xenon, each lamp mechanically fired twice each second. The flash duration is approximately 250 microseconds with an instantaneous beam output peak value of 30 million candlepower. The visual impression is that of a ball of light hurtling from the beginning of the approach light array toward the approach end of the runway at about 3000 miles per hour. The spectral energy distribution of a Xenon short arc lamp extends from 0.2 to greater than 1.4 microns, with strong lines and continuum

in the infrared. The high intensity of the flashing lights passing through the overlap of RBC filter response and emitted energy provide a noise display on the RBC indicator during periods of low clouds and visibility which prevents reliable use of the instrument. (The infrared filters which are placed between the photocell and reflector in an effort to reduce saturation of the cell due to skylight, are of the band-pass type allowing energy of long wavelength, 1. 0 to 2. 75 microns, to pass, but excluding the shorter wavelengths including most visible light.) Noise in the display is shown in Fig. 36A.

## Investigation of Electronic Means of EFAS Interference Suppression

### U. S. Air Force Unit

In October 1960, through the use of funds provided by the Air Force Cambridge Research Center, a solid state narrow-band amplifier manufactured by Barkley & Dexter Laboratories, Inc., was procured to replace the standard detector amplifier. Its purpose was to provide more efficient amplification while suppressing EFAS interference.

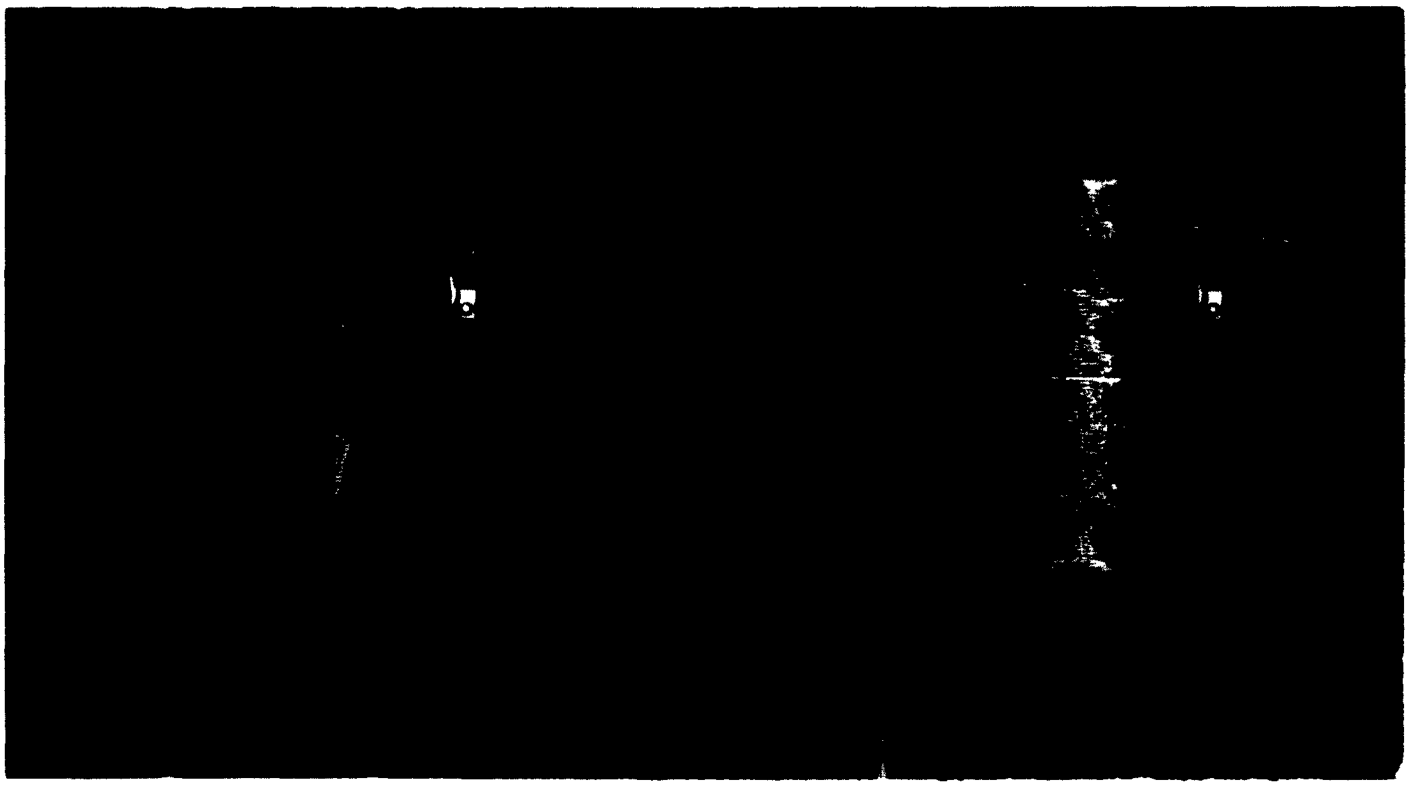
In a series of tests conducted at Atlantic City, no recognizable cloud signals were obtained with the unit in use. It was returned to the Air Force as unusable.

A similar unit was submitted for test by the Approach Visibility Project at Wright-Patterson Air Force Base, Ohio, during the same period. In correspondence with this project, the Weather Bureau Project Manager there described results as an almost undeviating noise output of 6. 5 volts regardless of cloud height. In a laboratory test, a signal generator was used to simulate a cloud signal and no readable output beyond a steady 6. 5 volt noise was ever obtained.

### U. S. Weather Bureau Unit

Beginning with the establishment of this project, the Weather Bureau's Instrumental Engineering Division cooperated in an attempt to electromechanically solve the problems of EFAS interference. This support was in the form of initial equipment and a continuing program of modifications and engineering consultation.

The Weather Bureau's RBC discriminator was a developmental model (WB IED Drawing 451.2328/A, February 2, 1960) connected in



(A) USWB DISCRIMINATOR OUT OF CIRCUIT
(B) USWB DISCRIMINATOR IN CIRCUIT

FIG. 36 ROTATING-BEAM CEILOMETER INDICATOR PRESENTATION, EFAS ON

the signal line between the output of the detector amplifier and the input circuits of the indicator. Designed primarily to improve the signal-to-noise ratio of the detected cloud signal, it also provided suppression of extraneous 60 and 120 cycle signals picked up by the detector. Ideally, with proper adjustment of the discriminator phasing controls and phasing of the projector lamp shutters, it should be possible to eliminate the interference from the EFAS.

Tests of the discriminator were conducted in available weather for about 18 months. It was determined that the unit tested did not provide entirely satisfactory performance.

Figure 36A illustrates EFAS interference with a cloud height measured at 220 feet and a daytime transmissivity 0. 70. Figure 36B is the response of the indicator with the discriminator in the circuit under the same weather conditions. The manner in which the cloud representation has been particulated is, of course, unsatisfactory.

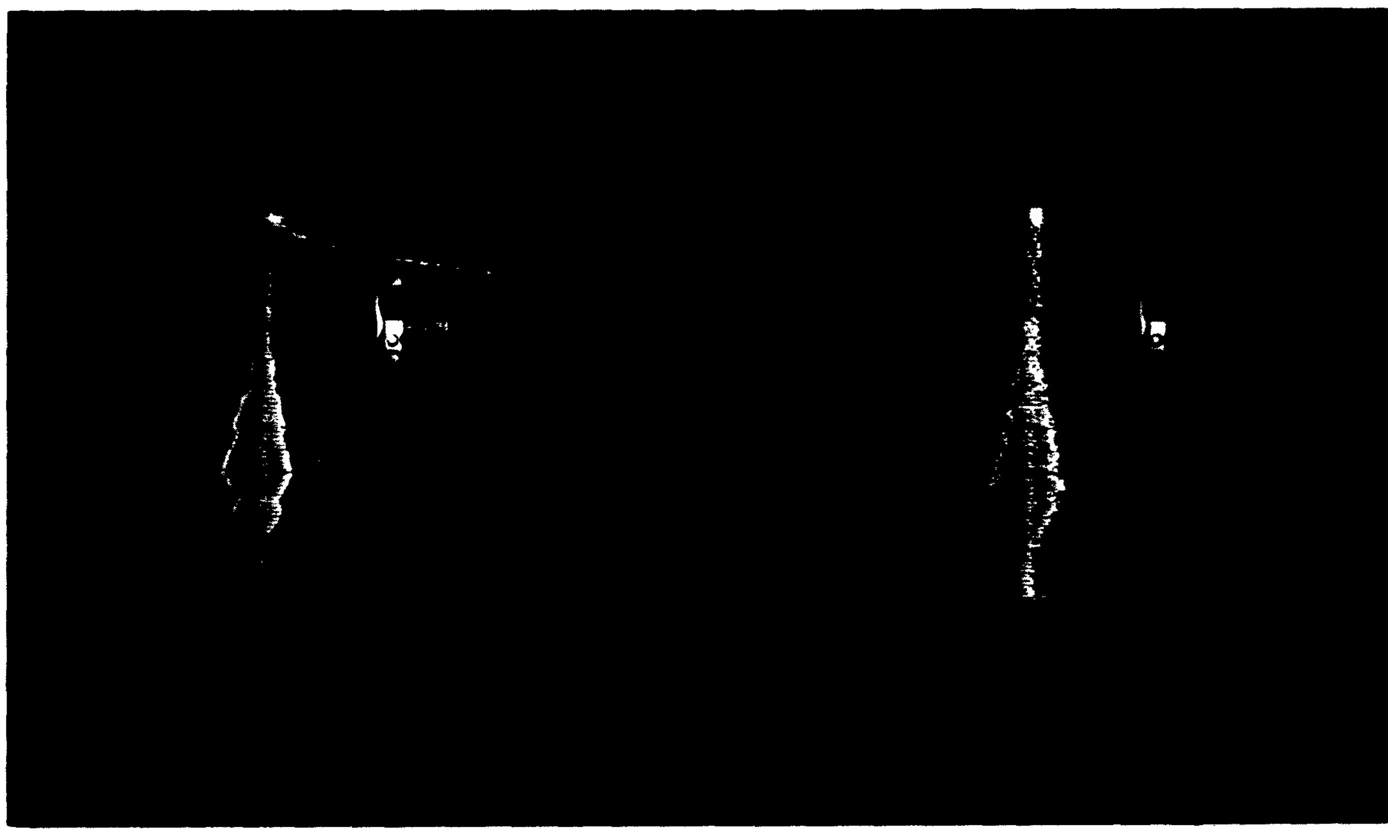
Figure 37A is a photograph of an RBC indicator response to low clouds during a daytime transmissivity of 0. 70. EFAS were off and the discriminator out of circuit. Figure 37B is the succeeding measuring scan under the same conditions with the discriminator in circuit. Undesirable ghost images have been produced, as well as a pattern which would erroneously indicate a multi-strata cloud deck; strata not indicated when the discriminator is out of circuit.

Despite continued efforts, the performance of the unit under evaluation could not be improved.

Investigation of Optical Means of EFAS Interference Suppression

No optical methods or equipment were made available to the project staff for evaluation. It was the impression of the staff that earlier inquiries made by other interested offices indicated that this area of approach to the problem might be less rewarding than the electronic approach.

There have been suggestions that filters which would pass a maximum of visible light but absorb the troublesome infrared radiation be put over the EFAS. Since such filters would reduce the visible light by about 15 per cent, it has been suggested that there might be a basic



(A) USWB DISCRIMINATOR OUT OF CIRCUIT
(B) USWB DISCRIMINATOR IN CIRCUIT

FIG. 37 ROTATING-BEAM CEILOMETER INDICATOR PRESENTATION, EFAS OFF

objection to this technique by some aviation interests even though the loss cannot be detected by eye. To overcome the loss caused by the filter, it has been suggested that the output of the EFAS be increased by a modification in the unit condenser. This method would tend to slightly decrease the flash tube lifetime, but in conjunction with a filter, would produce the same effective intensity as that currently provided.

# INSTRUMENTAL DEVELOPMENT AND MODIFICATIONS

## Transmissometer Receiver Blower Systems

### 1. Discussion of Problems

The transmissometer receiver blower system was developed to overcome the problem of wind-driven snow accumulating within the receiver hood. The standard hood heater was inadequate to prevent such accumulation during snow storms accompanied by high or gusty winds. Under these conditions snow could be forced into the hood heater too rapidly to be melted. On several occasions the snow piled up ahead of the lens to such an extent that light received from the projector was completely cut off and the accumulation had to be removed manually. During sub-freezing temperatures the transfer of heat along the hood was insufficient to produce melting for more than a short distance from the heater shell. Snowflakes and raindrops gathering on the lens surface materially reduced transmittance.

### 2. Attempted Solutions

The first experiments made to solve these problems utilized various types of baffles mounted around or ahead of the forward end of the receiver hood. While some degree of success was achieved, the weight of the baffles and their wind resistance caused appreciable variation in receiver alignment especially during gusty wind conditions. Wet snow collected on the baffles and partially filled the openings.

The first blower system was placed in operation November 1958 at Newark Airport. The hood fitting was built to use a lens cleaning opening cut in the receiver hood. This opening measured 2-9/16 inches lengthwise, and extended 4 inches around the hood. In other respects the fitting dimensions were approximately the same as those built at Atlantic City. In the horizontal plane, the 2-inch air supply tube was joined to the hood fitting at such an angle as to be almost tangent to the bottom of the hood, while in the vertical plane, the tube meets the fitting at an angle of about 60° (Figs. 4 and 38). The combination of sharp angle and tangential entry would probably produce a spiral motion of air forward along the hood and would result in removing the snow from all inner surfaces. An opening cut into the side of the fitting, opposite the entry point of the air supply tube, facilitated lens cleaning.

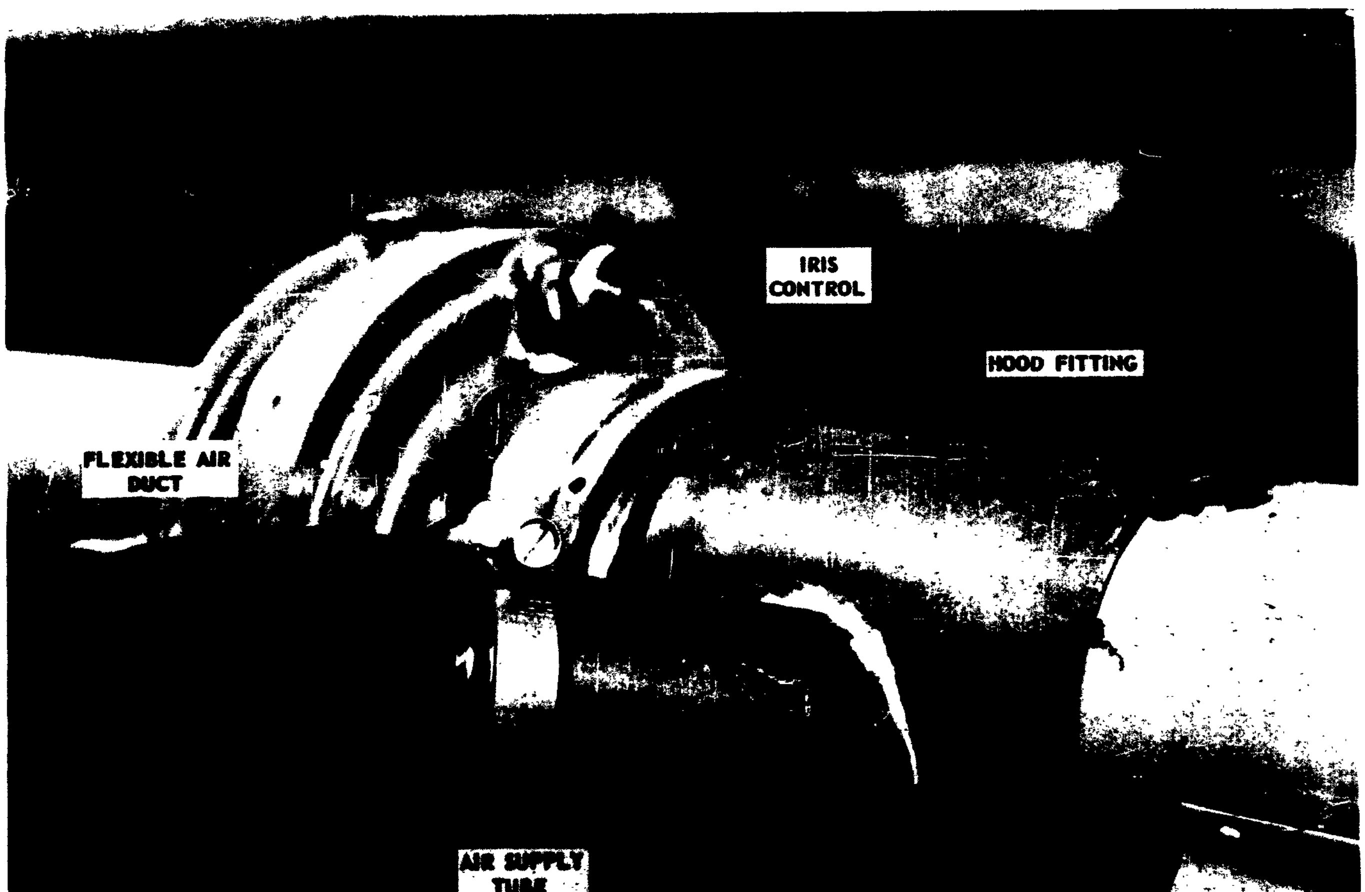



FIG. 38 DETAIL OF BLOWER SYSTEM HOOD FITTING

The centrifugal fan blower employed at Newark Airport was of the type originally supplied for use with the USWB telepsychrometers. While it was believed that a fan producing a greater airflow would be more dependable under all conditions, no such unit was readily available in fractional horsepower sizes at that time. The ILG, Type 6S N-924 fans used at Atlantic City, however, have a free-air output of 63cfm at 3200rpm.

A conclusive statement as to the efficacy of the blower system cannot be made at present because of the lack of data. Since the installations were completed, sufficiently severe weather conditions have not occurred to permit complete evaluation. During the period of heaviest snowfall and high winds, winter 1960-61, a field power failure incapacitated the blower systems as well as the transmissometers. However, no spotting or streaking on the receiver lens has been observed since the blowers have been in use. This is considered reliable evidence that precipitation has been unable to penetrate the airstream to reach the lens.

The blower system has also improved the operation of the transmissometer by eliminating the heat shimmer effect produced by the hood heater. This effect occurs most frequently during periods of light winds in cold weather. The concentrated output of the hood heater produces a bubble of warmer air within the hood and results in an unstable response to visibility conditions. Movement of air by the blower keeps conditions uniform within the hood and eliminates the heat shimmer.

## Transmissometer Projector Hood Modifications

### 1. Discussion of Problems

The transmissometer projector utilizes a high intensity sealed reflector lamp and it must be protected by a hood to reduce glare produced by the presence of litho- or hydrometeors.

The projector hood as originally designed (Fig. 39A) reduced the problem of glare and protected the lamp lens from precipitation. The use of the hood presented a new problem; that of birds using the hood as a shelter. Experience proved that one persistent creature can incapacitate the transmissometer system and all airfield operational and meteorological facilities dependent on the instrument. Large birds render the system useless as their bodies intercept the greater part of the light beam. Smaller birds cause a variation of several per cent in the indicated transmittance which could be erroneously, and hence dangerously, attributed to natural variations.

## 2. Attempted Solutions

Later models of the transmissometer were equipped with a modified hood as indicated in Fig. 39B. This unit reduced but did not solve the bird problem. They continued to roost on the tower platform in the path of the light beam.

In an attempted solution to the problem at Atlantic City, two hoods were modified as indicated in Fig. 40. A disk of 1/8 inch plate glass was mounted vertically at the forward end of the hood. This modification successfully countered the birds, but the inner surface of the disk was covered with moisture during periods of heavy rain.

The simplest, most economical, and most effective solution appears to be that of remounting the projector and hood (Fig. 39B) as far forward as possible on the tower shelf. Little area would then be available for the birds to roost.

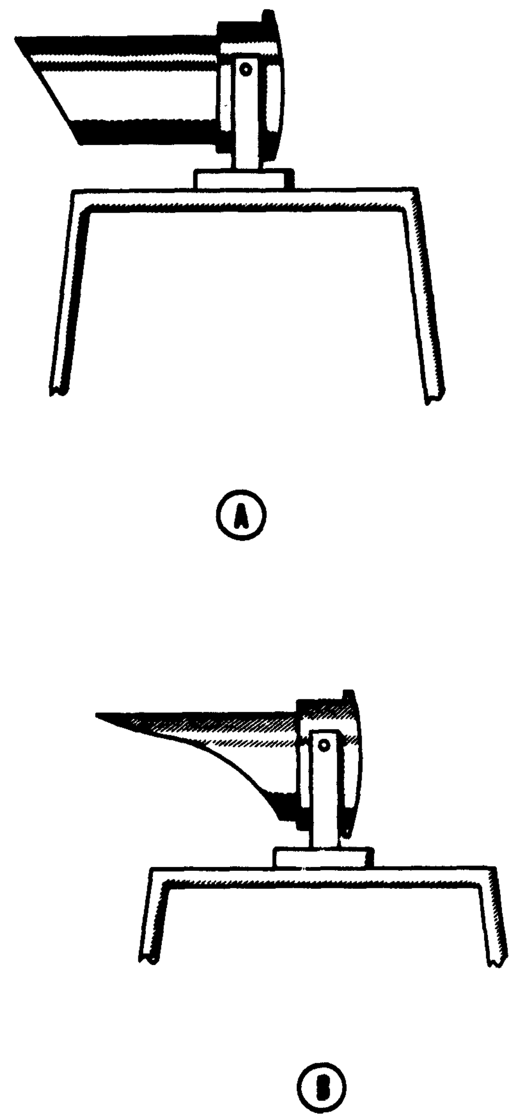



FIG. 39 TRANSMISSOMETER PROJECTOR HOOD MODIFICATIONS

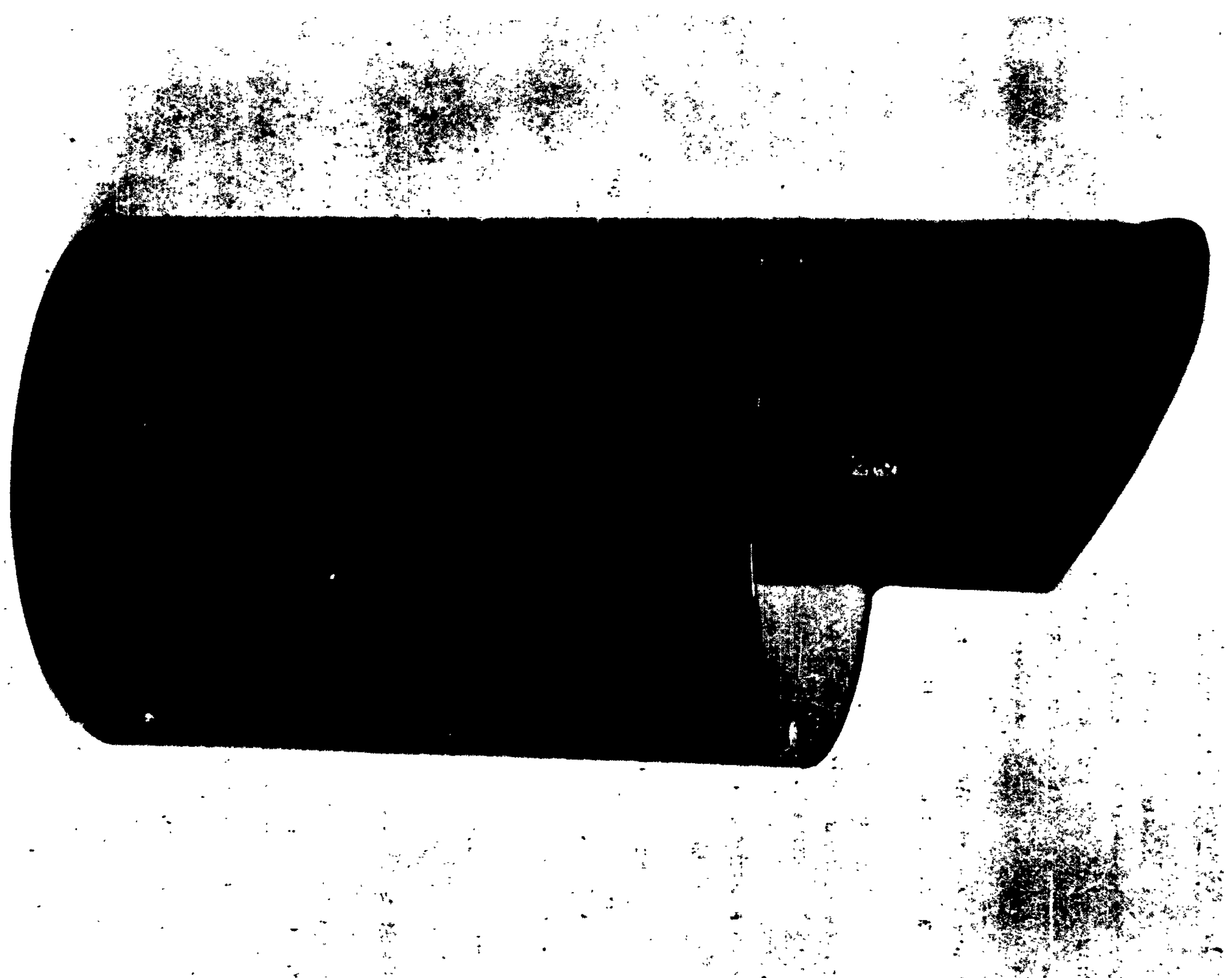


FIG. 40 TRANSMISSOMETER PROJECTOR HOOD WITH GLASS INSERT

## The Significance of Transmissometer Background Noise

### 1. Discussion of Problem

Indicated transmittance will contain, to a certain extent, an error contributed by ambient illumination surrounding the transmissometer receiver, signal line noise, and noise inherent in the receiver. This error can be isolated when the projector lamp is off, but in ordinary operation of the transmissometer system it is part of the gross indication of transmittance. The background error must be subtracted from the gross indication to obtain accurate transmittance.

Background error can vary from system to system. Auxiliary devices which use transmissometer systems such as an ALCH/RVR computer, must include circuitry to eliminate the background effect. The additional features increase the cost of the devices although they might not be required at locations where the background error is neglibible.

The purpose of this investigation was to determine the significance of the background error in the four transmissometer systems at Atlantic City. It is anticipated that the results could provide some basis for application to future computer design.

### 2. Data Acquisition

Data were collected by recording terrain illumination in foot-candles (ft. c.), and background count in pulses per minute (ppm) from four transmissometer systems. The background count and the simultaneous illumination record were obtained at random intervals throughout the day and night for a six-month period. To insure a uniform background count comparison, a pulse counter was connected to each of the transmissometers through a panel selector switch. Activation of the pulse counter grounded the signal line of the selected transmissometer, de-energizing the projector lamp. After the lamp cooled a one-minute period of counting began. Upon completion of the cycle the system was automatically restored to normal operation. A total of 1374 background readings were obtained: 1062 day and 312 night. A background count was not considered valid when a transmissometer was inoperative or indicated a doubtful transmittance.

### 3. Data Analysis

Table XX contains the tabulated results of data collection. The background count infrequently exceeded 20 ppm, or 1/2 of 1 per cent transmittance. The largest background counts, as anticipated, accompanied the greatest illumination. Night background counts were effectively zero with the exception of T1 which proved to be an inherently noisy system.

A decision was made to examine the effect of the derived background counts on certain critical points of runway visual range (RVR). Since a background count of 30 ppm was an extreme value and represented the most pessimistic situation, it was used in the test analyses. In the transmissometer systems currently in use, 4000 ppm = 100 per cent transmittance. Therefore, a background count of 30 ppm represents a correction to the gross indication of transmittance ($T_c$) of -0. 0075.

A transmittance of 0. 68 was selected as critical because it is at this point that the transition to the RVR contrast curve[1] takes place for day conditions, maximum runway light intensity, and a baseline of 500 feet (Fig. 41). Under similar conditions, other critical transmittance values are 0. 35 and 0. 49, RVR minimum values of 2000 feet and 2600 feet, respectively. In examining these areas of RVR with the introduction of a $T_c$ = -0. 0075, it was determined that there would be a maximum error of 60 feet in RVR if the $T_c$ were not subtracted. This would be at the highest, least critical range of transmittance. Lesser errors would result at the lower, more critical values of transmittance.

In the use of the contrast concept in RVR, it is at about a transmittance of 0. 78 with maximum runway light intensity and a 500-foot baseline, that the maximum RVR value, which is disseminated, occurs. This and other points along the contrast curve were examined in consideration of $T_c$ = -0. 0075, and the results listed in Table XXI. Under these conditions, the maximum error in RVR was about 234 feet. Again, this was a maximum error in the least important area of RVR.

[1]During the day a dark object is more apparent to an observer than is a bright light at higher ranges of visibility. To take advantage of this better guidance under these specific conditions, the RVR contrast concept has been utilized. The RVR contrast curve refers to RVR values based on the visual contrast of targets <u>other</u> than the high intensity runway lights.

# TABLE XX

## TRANSMISSOMETER BACKGROUND COUNT GROUPED BY CLASSES OF ILLUMINATION AND PULSES PER MINUTE

1374 total cases: 1062 Day; 312 Night

| | Background Count in Pulses Per Minute | Terrain Illumination in ft. c. < 1 | 1-10 | 11-200 | 201-1200 | > 1200 |
|---|---|---|---|---|---|---|
| | 0 | | | | | |
| | 1-5 | 84 | | 11 | 40 | 17 |
| Transmisso-meter 1 | 6-10 | 1 | | | 13 | 102 |
| | 11-15 | | | | 3 | 43 |
| | 16-20 | | | | 6 | 12 |
| | 21-25 | | | | 1 | 7 |
| | 26-30 | | | | 2 | 1 |
| | > 30 | | | | 2 | 1 |
| | 0 | 11 | | 1 | 2 | 2 |
| | 1-5 | 73 | | 10 | 62 | 64 |
| Transmisso-meter 2 | 6-10 | 2 | | | 3 | 75 |
| | 11-15 | | | | 7 | 30 |
| | 16-20 | | | | 3 | 12 |
| | 21-25 | | | | 4 | 2 |
| | 26-30 | | | | 2 | |
| | > 30 | | | | | |
| | 0 | 58 | | 6 | 26 | 2 |
| | 1-5 | | | 4 | 40 | 58 |
| Transmisso-meter 3 | 6-10 | | | 1 | 15 | 97 |
| | 11-15 | | | | 3 | 17 |
| | 16-20 | | | | | |
| | 21-25 | | | | | |
| | 26-30 | | | | | |
| | > 30 | | | | | |
| | 0 | 50 | | 5 | 16 | 3 |
| | 1-5 | 32 | | 4 | 48 | 93 |
| Transmisso-meter 4 | 6-10 | 1 | | | 9 | 54 |
| | 11-15 | | | | 3 | 9 |
| | 16-20 | | | | 1 | 8 |
| | 21-25 | | | | | |
| | 26-30 | | | | | |
| | > 30 | | | | | |

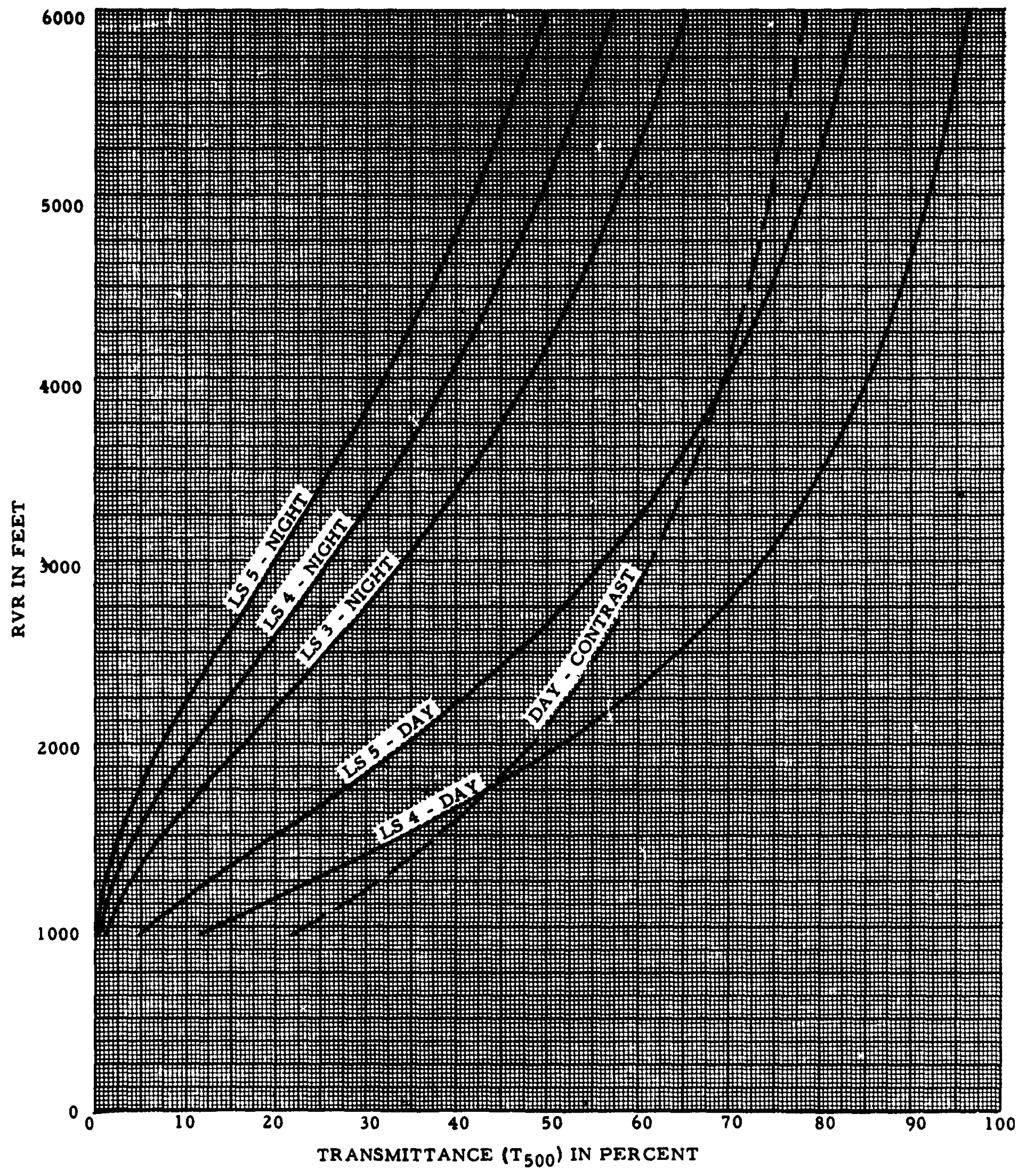



FIG. 41 CURVES, BY LIGHT INTENSITY AND CONTRAST, OF RVR VS. $T_{500}$

## TABLE XXI

## EFFECT OF TRANSMISSOMETER BACKGROUND ON RVR

| $T_{500}$ Corrected For Background | $T_{500}$ Uncorrected For Background | RVR Based On Runway Light Setting 5 (10,000 Effective Candlepower) Day (feet) | Maximum Error (feet) |
|---|---|---|---|
| 0.68 | | 3830 | |
| | 0.6875 | 3890 | 60 |
| 0.35 | | 2010 | |
| | 0.3575 | 2050 | 40 |
| 0.49 | | 2610 | |
| | 0.4975 | 2650 | 40 |

| $T_{500}$ Corrected For Background | $T_{500}$ Uncorrected For Background | RVR Based On Day-Contrast (feet) | Maximum Error (feet) |
|---|---|---|---|
| 0.78 | | 5837 | |
| | 0.7875 | 6071 | 234 |
| 0.75 | | 5041 | |
| | 0.7575 | 5222 | 181 |
| 0.65 | | 3366 | |
| | 0.6575 | 3459 | 93 |
| 0.55 | | 2426 | |
| | 0.5575 | 2482 | 56 |
| 0.44 | | 1766 | |
| | 0.4475 | 1804 | 38 |

where $T_c$ = -.0075

As a result of these studies, it appeared that the significance of background noise is negligible in the transmissometer systems at NAFEC.

Investigation of the National Bureau of Standards Expanded Scale Transmissometer Indicator

1. Discussion of Problem

Modern aircraft have increased the need for realistic landing and takeoff airfield weather minimums contingent with economy and safety; therefore, greater dependence must be placed on the accuracy and sensitivity of remote weather measuring instruments such as the transmissometer. It was in this interest that the National Bureau of Standards (NBS) modified the existing transmissometer amplifier circuit and developed an expanded scale indicator (Reference 17). The sensitivity of the former is relatively unsatisfactory at the lower end of the scale, which is the most important area in the determination of airfield RVR minimums. For example, when the transmittance falls below 0.05 (about 1/16 mile, day meteorological visibility, transmissometer baseline 500 feet) either less discrete indications of visibility must be used, or a cumbersome dual sensitivity range must be introduced.

To counter this problem, the NBS redesigned the transmissometer indicator to the extent that the output was nonlinear. Its nonlinearity was almost logarithmic, but did not have the logarithmic handicap of too expanded a scale at the low end, and a packing effect at the high end. It was this modification that the project subjected to investigation. It appeared that the altered system might be useful in manual RVR utilization of the transmissometer as well as an input for some types of ALCH/RVR computers.

In considering an approach to this investigation, it was recognized that there was not unanimity of opinion among authorities in the field of meteorological visibility as to the optimum time constant to be used in sampling atmospheric transmission. Some have suggested very brief samples as being most realistic. Others, such as Mr. C. A. Douglas of NBS, have stated that the object of the transmission measurement is not to obtain a measure of the instantaneous transmission between the projector and receiver, but the transmission which is representative of the area. With respect to the design of the transmissometer indicator under examination, Mr. Douglas suggested that a valid measurement of performance could be obtained under equilibrium conditions rather than as a result of instantaneous samplings.

In order to respond to the two basic approaches to the problems of atmospheric transmission measurements, it was determined that the objectives of the investigation therefore, with standard field instrumentation, were to:

a. Determine the differences between the transmissions recorded by the expanded scale system and the unmodified system, based on virtually instantaneous readings. This was termed the "rigorous technique."

b. Determine the differences between the transmissions recorded by the expanded scale system and the unmodified system respecting the requirement for equilibrium conditions.

2. Instrumental Modification

A PEMCO transmissometer indicator, Serial No. 3-59, was modified to provide a nonlinear output in the manner suggested by the NBS. A conventional transmissometer recorder with conversion parts was used.

The modifications involved the following (symbols refer to Fig. 8-3, Instruction Book for Transmissometer, Reference 14):

R 210 bypassed and eliminated from circuit.

R 205A, R 205, and R 206 replaced by two Globar Varistors in parallel, shunted by a 3.9 megohm resistor and a 10 megohm potentiometer in series.

R 212 replaced by a 7K ohm resistor.

R 213 replaced by a 250K ohm resistor.

C 204 disconnected.

After the modifications were made, it was impossible to obtain an electrical zero indication. The zero-adjust potentiometer was of a resistance inadequate to establish the base value. The NBS determined that additional resistance was required in the R 213 leg of the bridge circuit. An additional potentiometer, R 213A, 50K ohms, was inserted in series with R 213 and a satisfactory electrical zero obtained. R 213 was relocated to the under side of the indicator

chassis and utilized as a coarse-zero calibrate adjustment, and R 213A was mounted in the R 213 position and used as the fine-zero adjustment.

An additional problem was the inordinate amount of time necessary to calibrate zero. Forty-five seconds was required for the charge to dissipate on C 203 and to permit the pen to move from the 100 per cent to 0 per cent reading. To accelerate the calibration procedure, an external push-button switch was inserted in the circuit which connected the cathode of V 201 to the chassis and decreased the full-scale traverse time.

### 3. Data Acquisition

The expanded scale indicator and recorder were placed in parallel with a standard unit as the control, and simultaneously provided with the pulse train of T2 and the master timing pulse. Prior to data acquisition, a bench comparison was made of the control indicator and expanded scale indicator. Results of this comparison are shown in Fig. 42. Following data acquisition, both indicators and recorders were taken to the NBS and another bench test was conducted (Fig. 42). The nature of these bench tests excluded all extraneous noise pulses as might be encountered with standard signal lines. In both tests the recorders were permitted to reach equilibrium for a time period in excess of 1 minute.

Periods of varying transmissivity conditions as measured by T2 were selected. The range of variation was almost great enough to include readings over the full scale of the recorder. These periods were examined on a semiautomatic data reduction device. For the rigorous technique, discrete values were determined at consecutive five-minute intervals without regard to rate of change of transmittance. Two hundred and sixty pairs of transmittances were thus obtained. For the approach to the problem which was mindful of Mr. Douglas' design factors, 53 pairs of data were obtained with the stipulation that there be equilibrium (no change in indicated transmittance for at least one minute prior to data time). To reduce all data to a common term, expanded scale readings were converted to equivalent standard transmissions through the use of a design curve (Fig. 43).

### 4. Data Analysis

Figure 44 depicts all data obtained through the rigorous technique. Although the expanded scale instrument was not designed

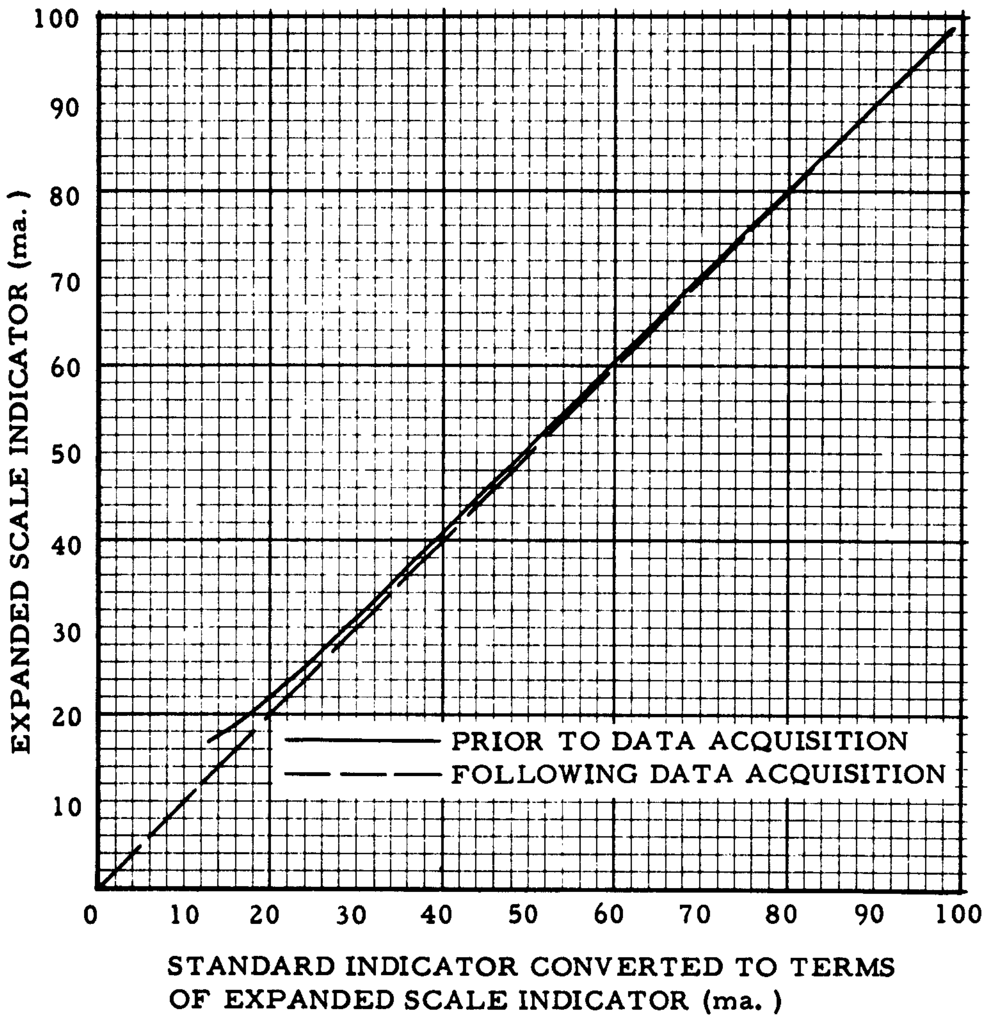



FIG. 42 COMPARISON OF EXPANDED SCALE INDICATOR

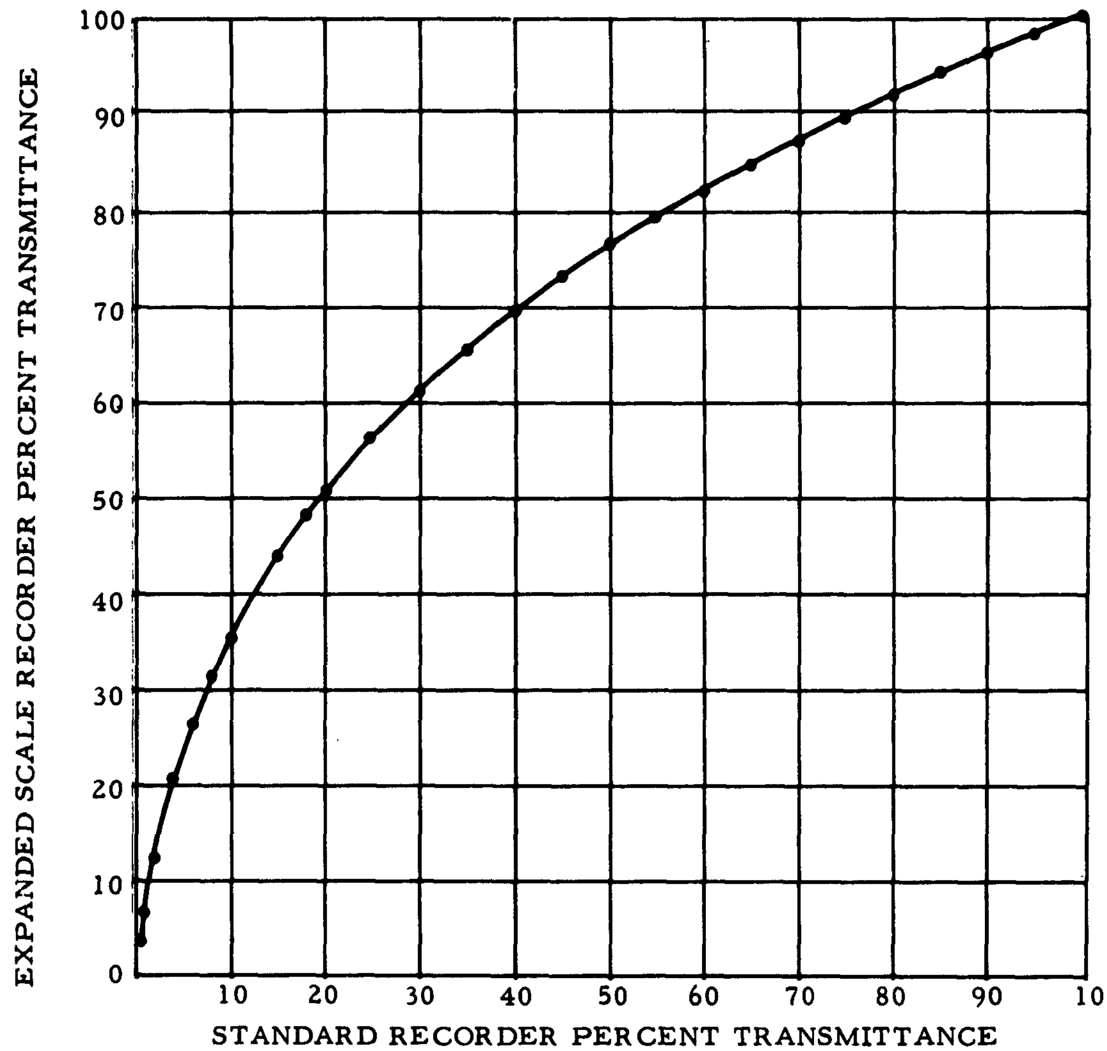



FIG. 43 DESIGN CURVE OBTAINED FROM TABULAR VALUES

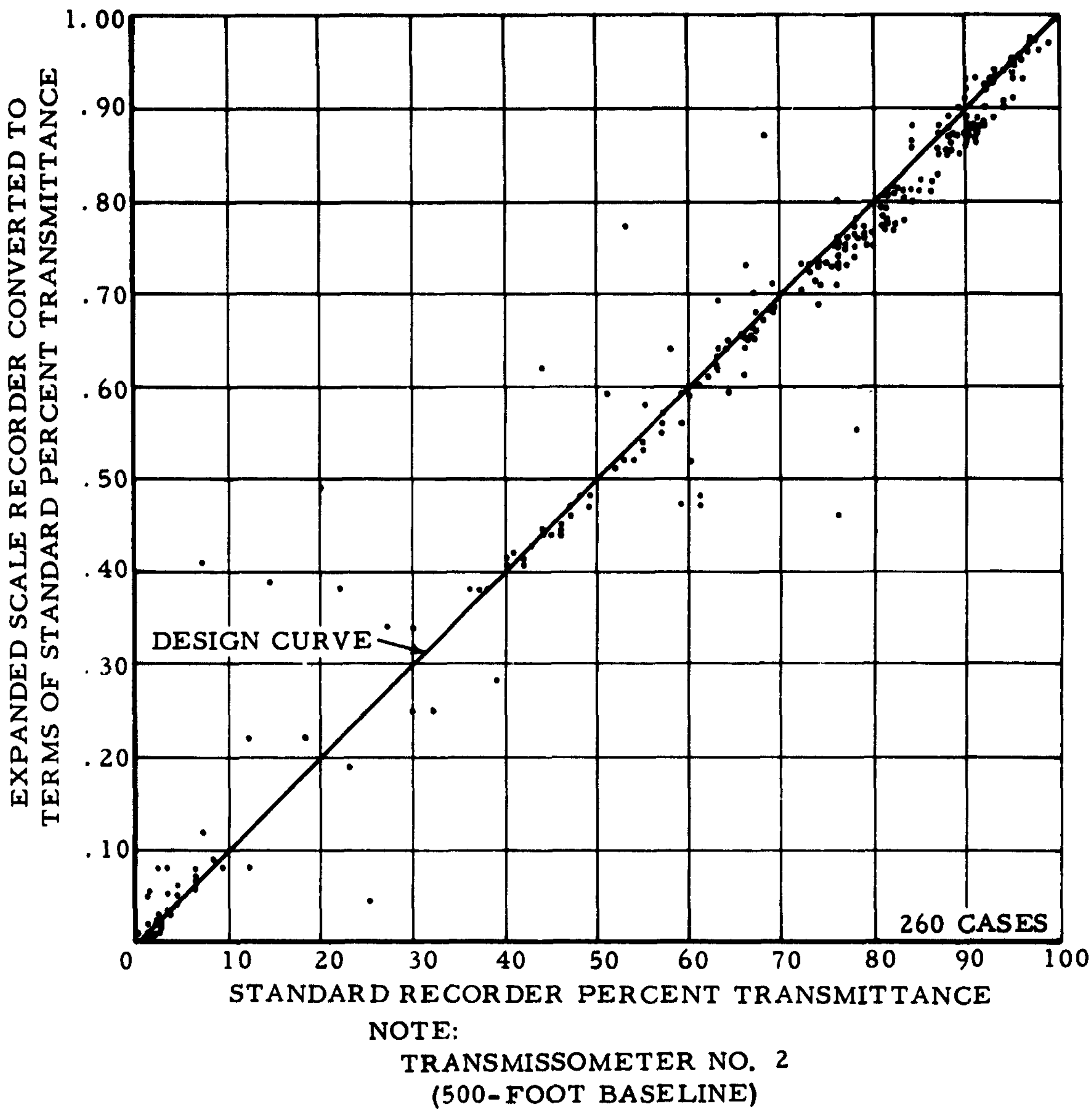



FIG. 44 PLOT OF DATA OBTAINED THROUGH RIGOROUS TECHNIQUES WITHOUT RESPECT TO INSTRUMENTAL EQUILIBRIUM

for instantaneous readings, and therefore a determination of the line of best fit was not considered applicable, there was moderate correlation with the standard instrument; correlation coefficient 0. 68.

Figure 45 is the representation of the data obtained using the criteria of one-minute unvarying transmission prior to observation (the equilibrium consideration). The correlation of the expanded scale instrument with the control unit was excellent, 0. 98. Despite the excellent correlation, the deviation of the experimental data curve from that of the design curve was great at the lower, more critical values (Fig. 46).

After consultations the reasoning was that: (1) because of the inherent inaccuracies at very low-scale readings in the standard unit that was being used as a control, results in the very low scale area might not be conclusive; and (2) four specific pieces of data appear to be the results of unusually excessive noise and tend to bias the limited data sample.

Hypothesis 2 was further investigated. The data were re-evaluated, and this time the potential noise data were neglected. Results were more favorable, the possible error generally within recorder accuracy (Figs. 47 and 48).

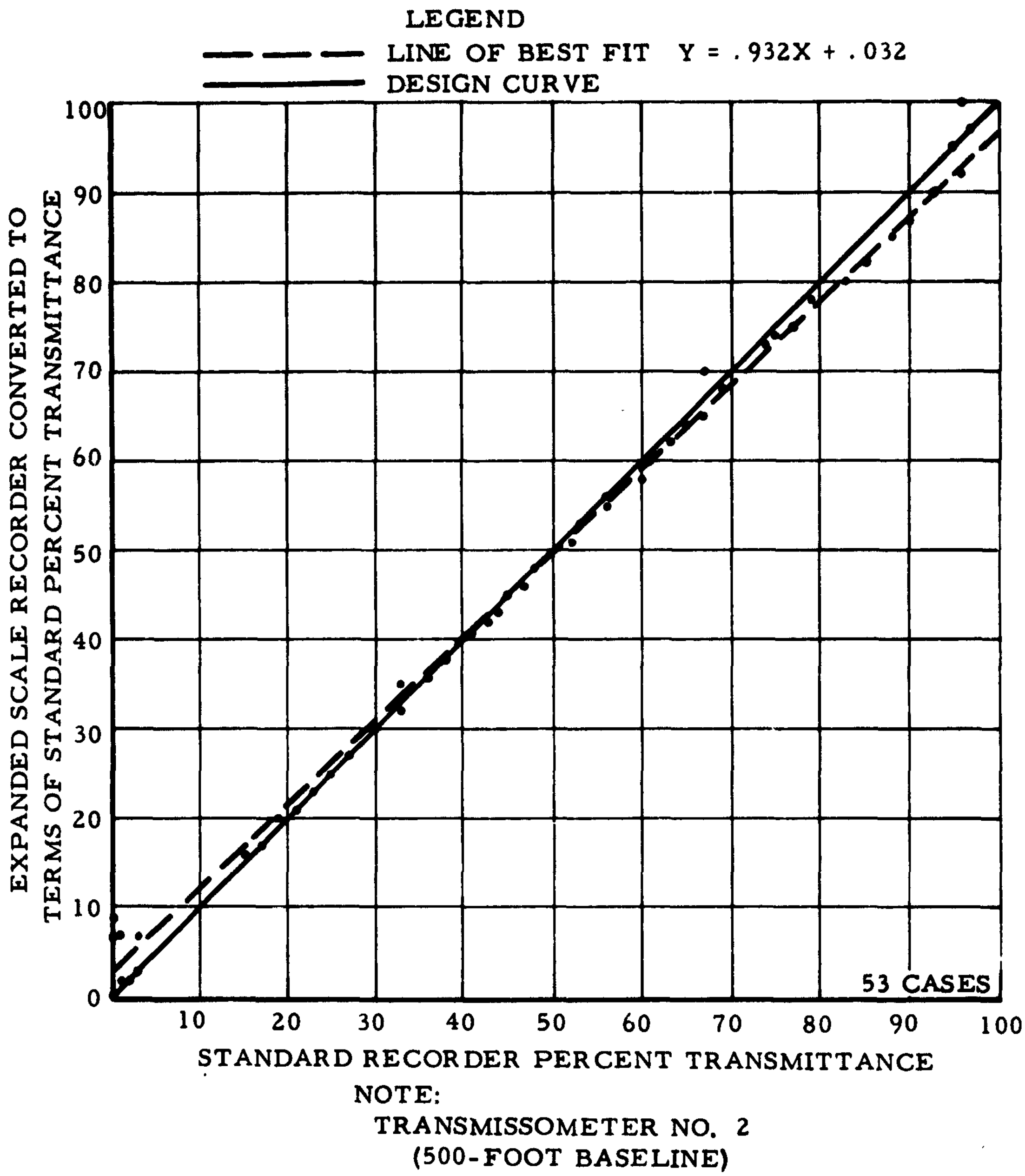
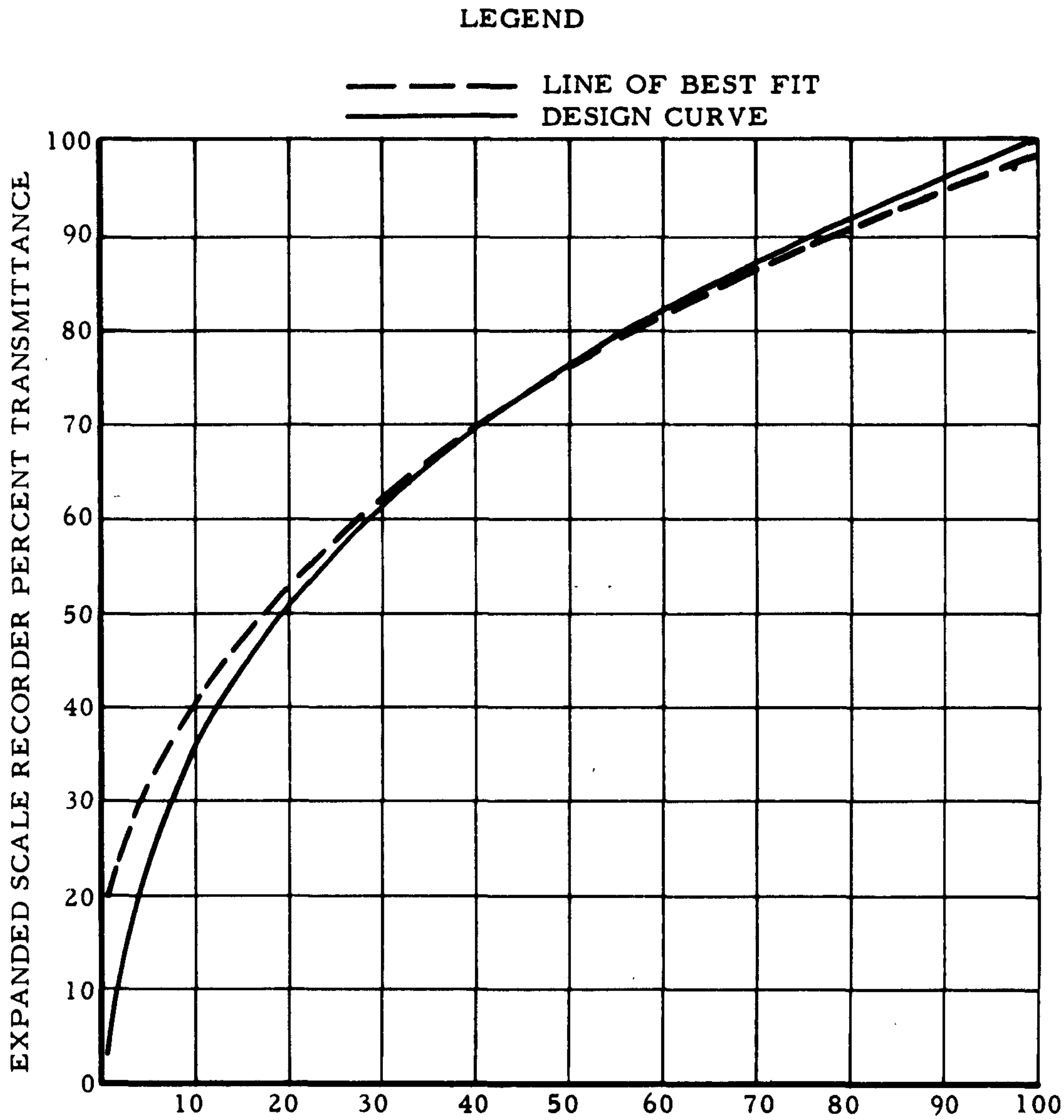
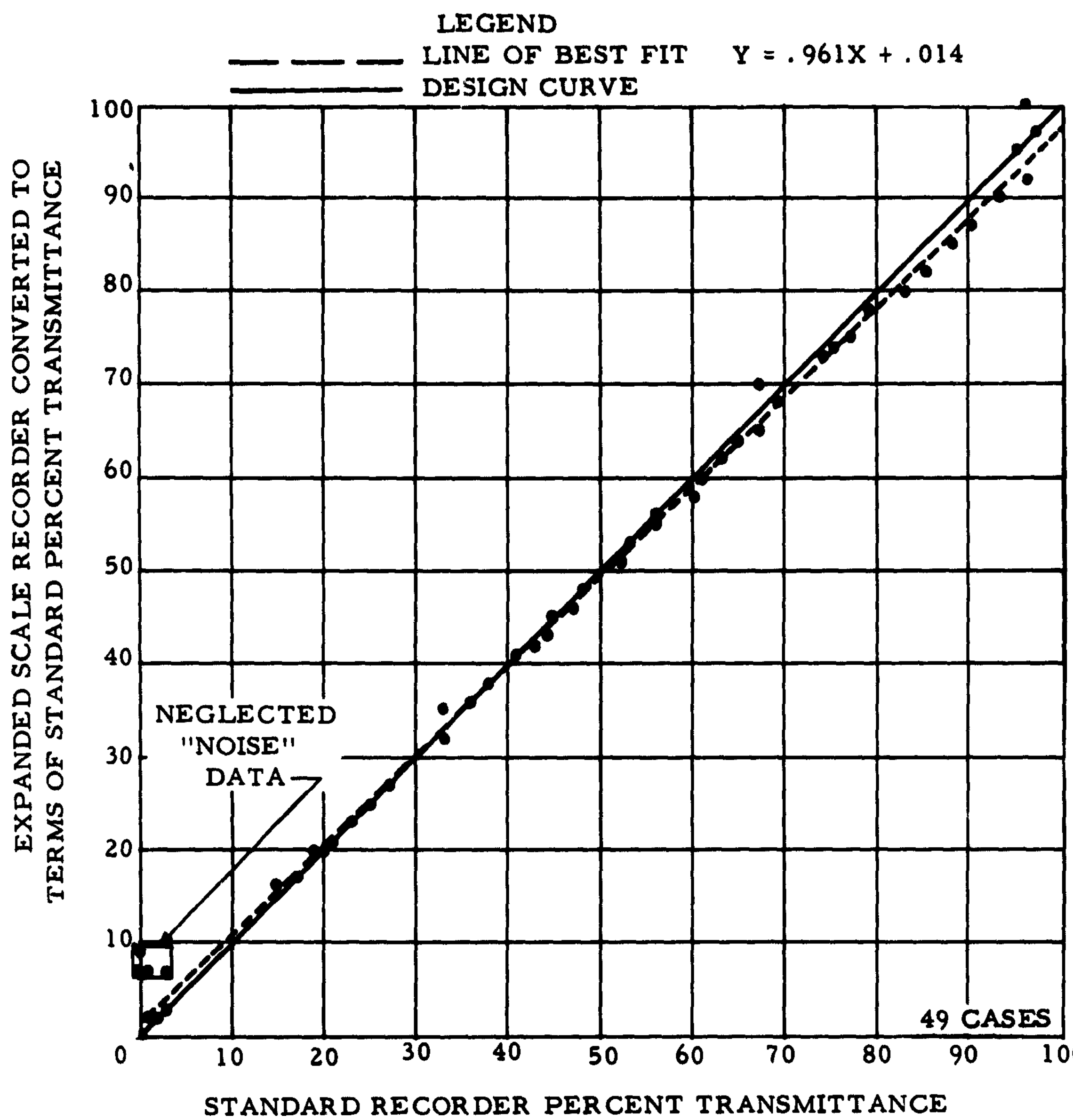



FIG. 45 PLOT OF DATA OBTAINED WITH RESPECT TO STIPULATION OF INSTRUMENTAL EQUILIBRIUM



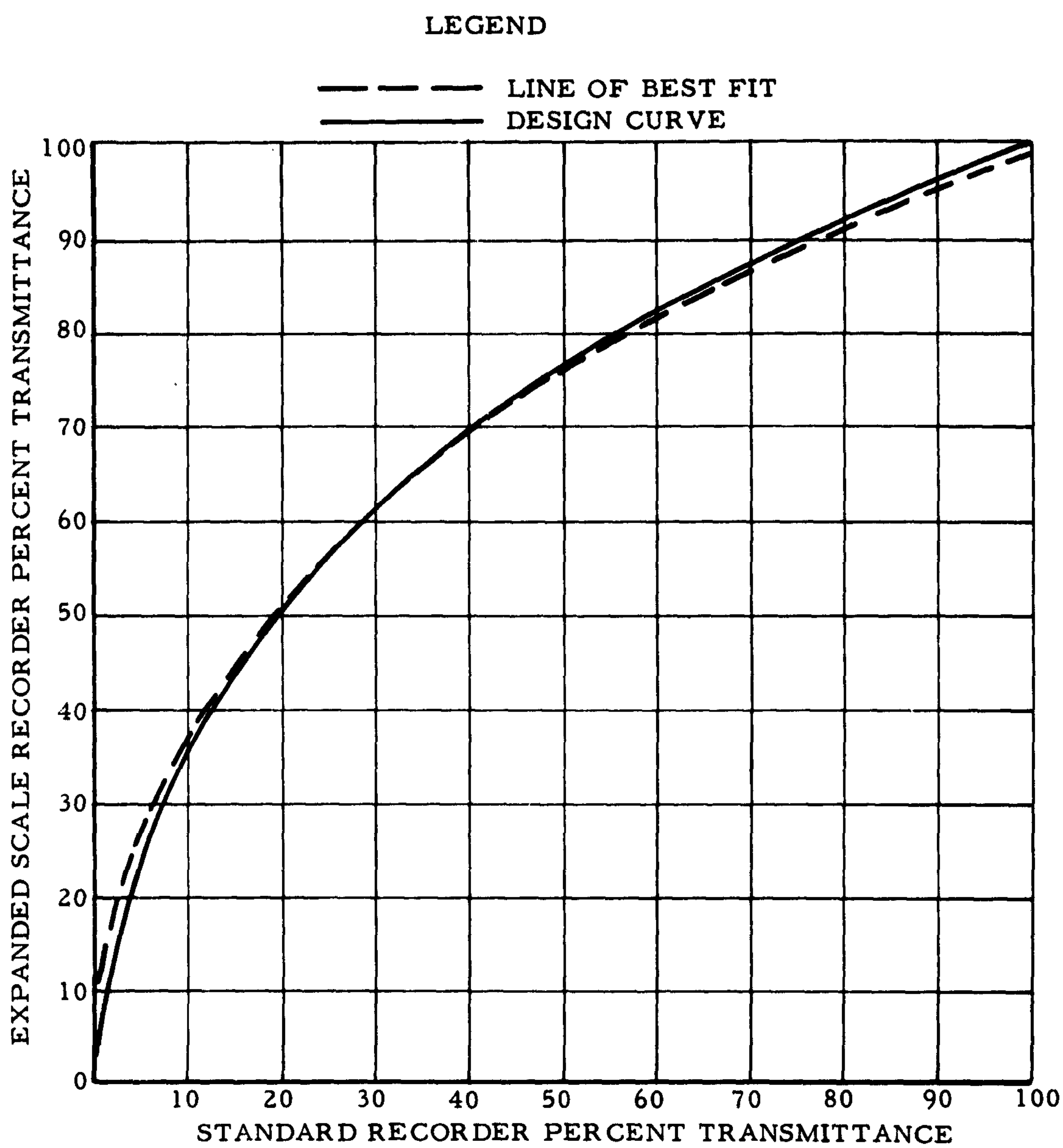

NOTE:
TRANSMISSOMETER NO. 2
(500-FOOT BASELINE)

FIG. 46 COMPARISON OF DESIGN CURVE AND LINE OF BEST FIT CURVE DETERMINED FROM EXPERIMENTAL DATA




NOTE:
TRANSMISSOMETER NO. 2
(500-FOOT BASELINE)

FIG. 47 PLOT OF DATA OBTAINED WITH RESPECT TO STIPULATION OF INSTRUMENTAL EQUILIBRIUM NEGLECTING POSSIBLE "NOISE" DATA




NOTE:
TRANSMISSOMETER NO. 2
(500-FOOT BASELINE)

FIG. 48 COMPARISON OF DESIGN CURVE AND LINE OF BEST FIT CURVE DETERMINED BY EXPERIMENT NEGLECTING POSSIBLE "NOISE" DATA

## CONCLUSIONS

As a result of the flight tests conducted to determine the applicability of the approach light contact height methods and constants which had been empirically derived from data collected during low ceiling and visibility conditions at Newark Airport, it is concluded that:

1. Sufficient test flight data were obtained at Atlantic City under low cloud conditions to permit a valid appraisal of ALCH constants and methods derived at Newark under like weather conditions.

2. The data sample size at Atlantic City for HF conditions was insufficient for extensive analysis, but was of sufficient size for elementary comparisons with Newark data.

3. The data sample size for snow conditions was too small for evaluation.

4. The low cloud and HF data sample acquired at Atlantic City reacted substantially the same as the like Newark sample when subjected to the same analytical procedures; it is therefore valid to base an evaluation of ALCH methods and empirical constants on the Atlantic City data.

5. The EFAS is constituted as the most likely light target in the ALCH concept.

6. The ALCH methods and empirical constants derived at Newark for low clouds apply to other locations and aircraft.

7. The qualitative appraisal of the limited HF category data acquired at Atlantic City indicates significant correlation with the empirical constants derived at Newark.

8. The system design presented in this report and Reference 1 is useful as the primary approach in the consideration of implementation of an operational system of ALCH.

Utilizing the basic data acquired for the evaluation of ALCH, investigations were made to determine optimum approach and runway light intensities for inclusion in an automatic intensity control design. From these investigations it is concluded that:

1. Automatic intensity control for approach and runway lights, using meteorological conditions as the prime controlling factor, is feasible.

2. A design for optimum intensity of approach and runway lights for varying meteorological conditions has been developed and presented.

Studies concerning the applicability of RVR determined from a transmissometer located at the touchdown area to landing roll, and takeoff operations included investigation of variations in transmissivity along the runway. Based on these efforts it is concluded that:

1. RVR determined from a transmissometer located at ILS touchdown is not always representative of the visual range encountered by a pilot during landing roll and takeoff operations.

2. If RVR is required in the touchdown or other specified area, transmissometers at locations other than that specified area will not satisfy the requirement.

3. In a runway complex having ILS facilities at each end, locating a transmissometer at each touchdown point, rather than a single system per runway, would significantly increase airfield utilization under low RVR conditions.

4. Airfield utilization is significantly increased when operational minimums are based on RVR rather than on prevailing meteorological visibility.

In an attempt to eliminate the severe interference to the rotating-beam ceilometer indicator caused by the electronic flashing approach lights, tests were made of electronic devices made available. It is concluded that:

1. The RBC discriminator units evaluated did not adequately suppress the EFAS interference to the ceilometer system during the test periods.

An objective of this task was to conduct studies and perform developmental work in the field of approach visibility instrumentation. Since the transmissometer is the prime instrument in this field, particular attention was given to its improvement. As a result of this effort it is concluded that:

1. The presence of a blower system to provide movement of air through the transmissometer receiver hood inhibits problems associated with snow accumulation, ice accretion, and heat shimmer.

2. To avoid the interference of birds and other small animals with the transmissometer projector, it is advantageous to have the projector based forward on its tower, flush with the edge of the tower shelf and equipped with the modified hood.

3. The magnitude of the transmissometer background count in the Atlantic City instrumentation was negligible in its effect on RVR.

4. While the NBS expanded scale transmissometer indicator does provide improved readability at low transmittances, it was not designed for instantaneous observations, and operational usefulness is therefore limited under rapidly varying conditions.

## RECOMMENDATIONS

It is recommended that:

1. The ALCH technique as described in this report and in Reference 1 be considered for operational use in the aviation weather service.

2. The results of this study on the automatic control of approach and runway lights be considered preliminary in nature and more extensive studies and tests be carried out prior to operational application.

3. A study be made of the contribution to error in RVR made by the transmissometer background at other locations, to determine if it would be economically practical and technically desirable to eliminate the background correction circuitry from future RVR computers.

4. RVR from more than one location along a runway should be provided as information to pilot and air traffic controller during landing and takeoff operations; and that these locations be in the touchdown zones at each end of the runway.

5. A study be made to determine the operational manner in which RVR information should be supplied from the additional systems

to interested personnel, and if such information should be operationally restrictive or only advisory.

6. Further investigations be conducted of electronic and optical means to develop an effective method of suppressing EFAS interference to the rotating-beam ceilometer system.

7. Transmissometer receivers be equipped with a blower system in those areas where snow accumulation or ice accretion causes obstruction problems.

8. In systems not already modified, the transmissometer modified hood projector be mounted forward, flush with the tower shelf, and equipped with the hood.

9. The time period over which varying transmissivity conditions should be measured be further examined with respect to specific operational applications.

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## GLOSSARY

$\alpha$ — Angle of the line of best fit glide slope with the plane of the runway.

ACY — Designator for Atlantic City Airport.

ALCH — Approach light contact height. The height above the ground at which a pilot making an ILS or GCA approach can expect to see at least a 500-foot segment of the designated approach light system with certain probabilities.

Allard's Law $$E_t = \frac{I\,(T_B)^{V/B}}{V^2}$$

where $E_t$ = the pilot's visual illuminance threshold in lumens ft. $^{-2}$;
$I$ = effective intensity of light target in candlepower;
$T$ = the per cent of atmospheric transmission;
$V$ = the pilot's slant visual range in feet;
$B$ = the transmission path length in feet.

AMB — Airways Modernization Board.

ANDB — Air Navigation Development Board.

AWRP — Aviation Weather Research Project.

$\beta$ — Cockpit cutoff angle, 15° in this report.

B — Transmission path length in feet. In practice, the transmissometer baseline.

C — $\dfrac{\text{Log } E_t - \text{Log } I}{2}$ A constant derived from Allard's Law incorporating those parameters which for reasons of accuracy or practicality cannot be determined instrumentally.

$C_p$ — C value at probability p.

cp — Candlepower.

| | |
|---|---|
| D | Minimum guidance segment of approach lights sighted, 500 feet in this report. |
| Day | $E_g$ equal to or greater than 1 foot-candle at Atlantic City, and greater than 10 foot-candles at Newark. The difference is photometrically insignificant. |
| EFAS | Electronic Flashing Approach Light System. |
| $E_g$ | The illuminance received on a horizontal surface, measured in foot-candles. |
| $E_t$ | Visual illuminance threshold. The minimum illuminance (luminous flux density) at the eye of an observer required from a source of small angular size in order that this source can be detected. |
| $E_{t_p}$ | Visual illuminance threshold at probability level p. |
| EWR | Designator for Newark Airport. |
| ft. c. | Foot-candle. |
| GCA | Ground-controlled approach. |
| $H_{AR}$ | The height, in feet, of the aircraft above the ground determined from the GCA radar photograph made at the instant of a pilot's report of approach light contact. |
| $\bar{H}_c$ | Mean value, to the nearest foot, of four consecutive measurements of cloud height by the middle marker RBC. |
| $h_p$ | ALCH based on Allard's Law pertaining to probability level p. |
| $H_p$ | ALCH based on low-cloud category linear regressions pertaining to probability level p. |
| HF | A homogeneous mixture in the atmosphere combining one or more elements of fog, smoke, or haze. |
| I | The luminous intensity of the light target in candlepower. |

IFR Instrument flight rules.

ILS Instrument landing system.

LS The intensity setting of the approach or runway lights, using index numbers 1 through 5.

NAFEC National Aviation Facilities Experimental Center, Atlantic City, N. J.

NBS National Bureau of Standards.

Night $E_g$ less than 1 foot-candle at Atlantic City, and equal to or less than 10 foot-candles at Newark. The difference is photometrically insignificant.

p Used as a subscript, and represents a general probability value.

r Linear correlation coefficient.

RBC Rotating-beam ceilometer system.

RER Horizontal range of the aircraft from the end of the runway at the instant of approach light sighting.

RTD Horizontal range of the aircraft from the point of ILS touchdown at the instant of approach light sighting.

RVR Runway visual range. The horizontal distance a pilot would be able to see from his changing point of observation as he moves along the runway. Values are based on the intensity of the high-intensity runway lights, or on the contrast of other targets, whichever provides the greatest horizontal visual range.

$T_B$ Atmospheric transmission. The fraction of original luminous flux remaining in a beam of light after passing through a distance B of the atmosphere. B=500 feet at Atlantic City, and 810 feet at Newark.

TD Touchdown. The theoretical intersection of the ILS glide slope with the plane of the runway.

$T_c$ Correction to the gross indication of transmittance, based on the contribution of background.

TSO Technical Standard Order.

V Slant visual range. The distance from the pilot to the farthest approach light bar observed.

$V_p$ Slant visual range at probability p.

WBAS Weather Bureau Airport Station.